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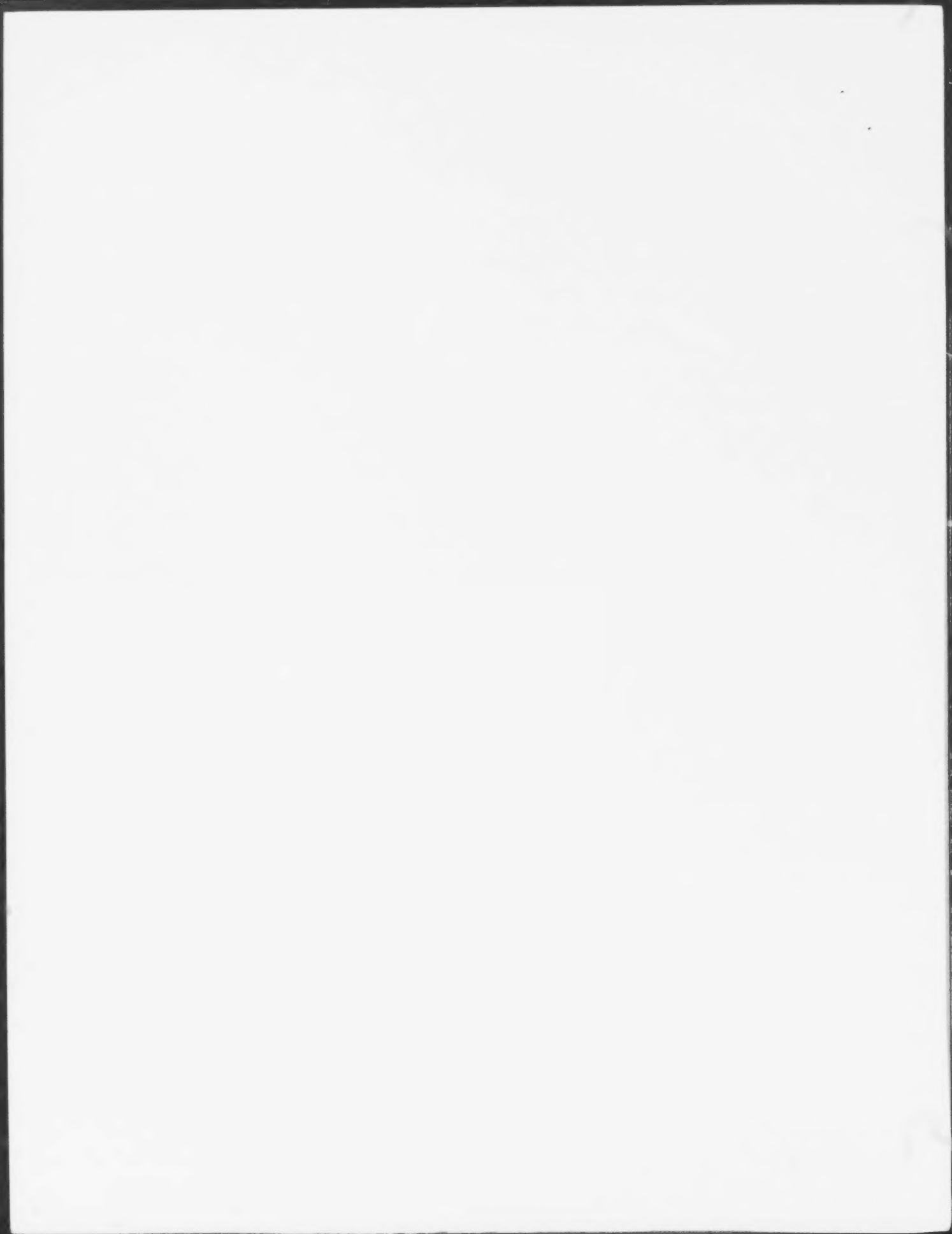
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**DEVELOPMENT OF HARD WHITE BREAD
WHEAT WITH SPROUTING RESISTANCE**

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“DEVELOPMENT OF HARD WHITE BREAD WHEAT WITH SPROUTING RESISTANCE”

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Principal Investigator:

Dr. Pierre Hucl, Research Professor
Department of Plant Sciences/Crop Development Centre
University of Saskatchewan
51 Campus Dr.,
Saskatoon, SK Canada S7N 5A8
E-mail: Hucl@sask.usask.ca
Telephone: 306-966-8667
Facsimile: 306-966-5015

Co-Investigators:

Dr. Maria Matus-Cádiz, Department of Plant Sciences/Crop Development Centre, U of S
Ms. Kathy Hanson, Saskatchewan Wheat Pool, Research and Development, Watrous
Ms. Connie Perron, Department of Plant Sciences/Crop Development Centre, U of S
Dr. Robert Tyler, Department of Applied Microbiology and Food Science, U of S

ABSTRACT

The objective of this project was to develop hard white bread wheat cultivars with high seed dormancy levels. Two hundred and eighty advanced lines were tested, fourteen (five percent) were entered into the Registration Testing system. Five of those lines were advanced into the official Registration Tests, all were withdrawn due to unsatisfactory yields. Although, no CWHW variety was developed during the course of this project. However, W98616 exhibited stronger seed dormancy than white-seeded cultivars AC Vista and Snowbird, similar to that of the red-seeded sprouting resistant cultivars, AC Domain and Columbus, but the grain yield was lower relative to registered CWRS and CWHW cultivars. An experiment was conducted in order to develop a seed dormancy-breaking protocol. It was found that chilling with 0.01 M KNO₃ was effective in over-coming dormancy in lines such as W98616 and lines with even higher dormancy levels.

Similarly, seventy-nine wheat genotypes for grain color values agronomic traits, grain protein and grain hardness, were evaluated. Fifty-eight percent of the Australian cultivars assessed produced whiter seed than the Canadian check variety, Snowbird. This suggests that we can improve on grain whiteness in Canadian germplasm. Seventy-seven percent of the variation in color was due to genotype and less than ten percent due to environment. Tests on the assessment for the level of stability of seed dormancy and color over environments for the equivalent of breeding lines revealed that the performance of genotypes was less consistent across years (G x Y) than across locations (G x L).

Abstract written by Program Manager Khalid Iftikhar, with SAFRR.

INTRODUCTION

Background information

The over-all objective of this project was to develop hard white bread wheat cultivars with CWRS wheat quality combined with levels of seed dormancy similar to those of the most dormant red-grained cultivars. Other objectives were to characterize the Hard White wheat CDC line W98616 as a source of very high seed dormancy and to study pigments in elite white-seeded lines.

Spring wheat grown in Saskatchewan has traditionally been red-grained. A shift in markets to the Pacific Rim region has resulted in the need for white-grained cultivars. All wheat produced in Australia is white-grained. All major wheat-producing regions in the USA are converting their germplasm to white-grain from red grain and have, in some cases, hired breeders specifically to run parallel programs along with the traditional red-grained wheat programs. This conversion started on a limited scale in the 1980's but has accelerated with the release of seven white-seeded winter wheat cultivars in Kansas by the late 1990's. North Dakota State University released a hard white spring wheat cultivar named 'Argent' and a number of hard white wheat cultivars have been released in Montana, Idaho and Washington state.

The white-grained spring wheat cultivar 'Norquay' was released in Canada in the mid-1970's but deregistered due to non-CWRS quality coupled with kernel distinguishability problems with the CWRS class. The white CPS class was created in 1985 to address lower-protein markets. Two CWRS-analog cultivars (Snowbird and Kanata) were registered by AAFC-CRC in 2004.

White wheat germplasm has traditionally had poor pre-harvest sprouting resistance and this has been a draw-back for the potential development of white wheats adapted to Saskatchewan. The Crop Development Centre developed a unique white seeded line. This line has sprouting resistance equal to the

CWRS cultivar Columbus. The Saskatchewan Wheat Pool and the CDC jointly developed white-grained lines with CWRS-type quality, starting in 1996. This project was designed to incorporate the high dormancy trait into the CDC/SWP elite material.

Canada stands to lose market share in the Pacific Rim region if it cannot provide white seeded wheat cultivars for bread or dual purpose (noodle and bread) markets. The US is already at the commercialization stage but still does not have sprouting resistant cultivars available.

A 1999 study (MRAC/CW) estimated that ca. 3.2 million acres of CWRS wheat could be converted to CWHW cultivars by 2007-08. This acreage would represent 10% of all wheat grown in western Canada. If the study's assumptions are realistic, CWHW would be more widely grown than a number of existing wheat classes (CPSW, CWES, CWSWS, CWRW). In 2004 approximately 600,000 acres of CWHW were grown in western Canada.

In Saskatchewan, wheat usually ripens under warm, dry conditions that favor development of grain for bread making. However, the ripe grain can sprout in the spike when moist conditions delay harvest and promote germination. Pre-harvest sprouting of physiologically mature grain can occur during wet harvest conditions. For the period of 1978-88, the economic losses attributed to pre-harvest sprouting in the Canadian red spring wheat crop were estimated at about \$400 million (Derera 1990). Wetter than normal harvests in 2002 and 2004 resulted in sprouting and, subsequently, downgrading of wheat in Saskatchewan.

Pre-harvest sprouting can cause processing problems because of high levels of the starch degrading enzyme alpha-amylase (α -amylase). The action of the enzyme during baking reduces the water holding capacity of the starch, resulting in lower baking absorption (i.e., lower bread yield) and handling problems due to sticky dough properties (i.e., a more open coarse crumb structure and gummy crumb). Gummy crumb causes build-up on slicer blades and interferes with effective bread slicing. Loaf volume often is not affected by sprout damage, and can actually increase due to more rapid gas production during fermentation. All of the effects of α -amylase are exaggerated for baking processes with long fermentation times because α -amylase continues to degrade starch during the fermentation stage.

Seed dormancy is the main factor responsible for conferring pre-harvest sprouting tolerance to wheat grain. Seed dormancy is known as the temporary failure of a viable seed to germinate in a particular set of environmental conditions that later evoke germination when the restrictive state has been terminated. That is, dry, viable, and non-dormant seeds germinate readily when hydrated, but dormant seeds will not germinate. Incorporating seed dormancy into new red- and white-seeded wheat cultivars could reduce the economic losses associated with pre-harvest sprouting. Line W98616, selected from the cross AUS1408/RL4137, was developed at the Crop Development Centre, Department of Plant Sciences, University of Saskatchewan (Hucl and Matus-Cádiz 2002). This line was characterized as part of this project. AUS 1408, white-seeded wheat, and RL4137, red-seeded wheat, are both considered good sources of pre-harvest sprouting resistance. RL4137 is the source of elevated sprouting resistance in a number of CWRS wheat cultivars (e.g., Columbus, AC Domain, AC Majestic, Harvest).

Generally, dormancy in the mature seed of most modern cultivars of common bread wheat lasts only a few days and is lost before the seed is sown. There are, however, cultivars where seed dormancy can last for several months. From a practical standpoint, increased seed dormancy (the main basis for sprouting resistance) will result in poor stands when attempting to plant freshly harvested seed in the greenhouse for the purposes of single seed descent programs. Currently published protocols for breaking seed dormancy may not work for highly dormant germplasm (eg W98616).

With the introduction of the Canada Western Hard White Spring (CWHW) market class in Canada, kernel color has become an important discriminator between hard red (Canada Western Red Spring, CWRS) and hard white (CWHW) spring wheat classes. International markets, particularly in Asia where products such as steamed bread and noodle products predominate, often prefer white to red-seeded wheat (Crosbie et al., 1998). Australia is currently the largest world producer of hard white wheat (HW) (Teetaert, 2000). If HW wheat production increases to significant levels in Canada, then we stand to capture a larger share of the wheat export market. 'Snowbird' was registered as the first CWHW cultivar in Canada.

The NaOH color test can overcome the subjectiveness of visually classifying the grain color of troublesome wheat samples (Lamkin and Miller, 1980; DePauw and McCaig, 1988). Selecting for superior grain lightness in CWHW cultivars will depend, in part, on the existence of genetic variation for grain color. To date, little information is available on the presence of genetic variability for grain color in hard white spring wheat.

Red kernel color is controlled by up to three loci, located on chromosomes of homologous group 3, with partial dominance over white kernel color (Metzger and Silbaugh, 1970). In addition to three major loci controlling red seed color, there may be as many as six minor genes influencing grain color (Freed et al., 1976; Reitan 1980). Kernel color is known to be a highly heritable trait (Cooper and Sorrells, 1984), however, color is known to vary in its degree of lightness across environments. Wu et al. (1987) reported that kernel color of white wheat cultivars from northern China was darker when grown in the more humid region of the Lower Yangtze Valley. Wu et al. (1999) reported that some hard white winter experimental lines were found to be more sensitive to environmental changes than hard red winter check cultivars, but others were found with improved levels of color and color stability across environments when compared with hard white winter check cultivars. Peterson et al. (2001) documented variation in grain color in white winter wheat over an array of production environments and cultivars. Only one of 18 hard white cultivars grown over five locations in 1996 produced grain that was equal to or lighter than the color standard while only one of the 14 cultivars grown over six locations in 1997 had acceptable grain color. Little information is available to date on the nature of the G x E interaction in determining grain color in hard white spring wheat.

Selection for grain color in a HW wheat breeding program requires knowledge of the magnitude of the G x E interaction. If interactions between genotype and environment exist then genotypes selected as superior in one environment may not be superior in other environments (Baker and Kosmolak, 1977). A significant G x E interaction may be either (i) a non-crossover G x E interaction where the ranking of genotypes remains constant across environments and the interaction is significant because of changes in the magnitude of the response, or (ii) a crossover G x E interaction where a significant change in rank occurs from one environment to another. When selecting genotypes for wide adaptation, plant breeders look for a non-crossover G x E interaction or preferably the absence of a G x E interaction.

METHODS AND RESULTS

Standard small plot techniques were utilized in the evaluation of Hard White wheat experimental lines. The results of the breeding efforts are summarized below.

C-1 Lines advanced to the Registration Testing system (2000 to 2004)

We entered our first Hard White wheat line (SWP981061; BW784) in the Coop testing system in 2000. This line was higher yielding than AC Barrie and earlier maturing in our 1999 trials. In the 2000 Coop it yielded similarly to Neepawa (-9% of AC Barrie) but was the earliest line in the trial. This line was transferred to the Parkland Coop test in 2001 and evaluated as PT563. In 2001, PT563 yielded 10% less than Barrie with no maturity advantage. Hence, testing of this line was discontinued.

Two HW lines were entered in the 2000 WBWB pre-Coop test (SWP981052 and SWP981053). Both these lines were dropped due to quality deficiencies. The above-mentioned three lines represented the best material from the first cycle of populations developed jointly by the CDC and the Saskatchewan wheat pool.

In 2001, one line (HW00009) was advanced to the WBWB pre-coop Test. This line was subsequently tested as BW812 in the Western Bread Wheat Registration Test (pedigree = Argent/BW204) in 2002. This line was similar in yield (99.8%) to AC Barrie in the 2001 WBW'B' test; grown at 7 sites. In the 2002 WBW Coop (9 sites), however, it yielded significantly less, -19%. It is not clear what caused the yield collapse of this line. In any event, the testing of this line was discontinued. In addition to BW812, two lines were entered in the 2002 WBWB pre-Coop Test (HW01006 and HW01017).

We entered our third HWSW line (HW01006; BW821; pedigree = Argent/BW204) in the Coop testing system in 2003. This line yielded 95.1% of AC Barrie and 106.0% of EC Elsa in the 2002 WBW'B' test; grown at 6 sites. In the 2003 WBW Coop (12 sites), however, it yielded 92.1% of AC Barrie. It appears that BW821 followed the same pattern as its sister line BW812 when tested in the Coop system – declining yield performance with increased environmental sampling. Hence testing of this line was also discontinued. Five HWSW lines were entered in the 2003 WBWB pre-Coop test (HW02011, HW02025, HW02049, HW02061 and HW02063). Of these five lines, two (HW0211 and HW02025) were tested in the newly created 2004 Hard White Wheat Registration Test. Both lines were dropped due to marginal agronomic performance. A third line (HW02061) was entered in the 2004 Hard White B Test and is undergoing quality evaluation at the time of report preparation. In addition to HW02061, three other lines were entered in the 2004 HW'B' Test.

C1.1 Agronomic and quality performance of hard white wheat lines in Pre-Coop trials (1999 to 2004)

During the course of this project 280 advanced lines were tested at multiple sites each year. With the exception of 2003, six sites were the testing norm. In 2003 testing was limited to four sites as a result of the 2002 drought limiting seed supplies for the subsequent year's plantings.

1999:

A 36 entry, 2 replicate trial was grown at six sites (Kernen, Seed Farm, Lashburn, Watrous, Lake Lenore, and Brandon) in 1999. The Watrous site was lost due to herbicide injury. The data is expressed as a % of AC Barrie for yield and the remaining traits are expressed as a deviation from AC Barrie (Tables 1 and 2). Lines that were not advanced to the final stage of quality evaluation are not included in the Tables for the sake of brevity.

Pigmentation and polyphenol oxidase (PPO) data are summarized in Table 3. All test lines possessed a white seed coat based on a 5% NaOH test. Emphasis was placed on grain and meal color using a Hunterlab reflectance colorimeter, with consideration given to other meal properties such as yellow

pigmentation and free-lutein levels. Hunterlab color L and b values, obtained using whole grain samples, indicated that the lines were whiter and more yellow than the white-grained DNS check 'Argent'. Hunterlab color values, obtained using whole meal samples, indicated that the lines had whiter, less red, and similar yellowness relative to the checks. Carotenoid pigments and free-lutein levels in the test lines tended to be equal to or lower than in the CWRS check 'AC Barrie'. Polyphenol oxidase levels in the test lines tended to be equal to or higher than in AC Barrie.

2000:

A 20 entry, 2 replication trial was grown at six sites (Kernen, Goodale, Seed Farm, Scott, Watrous, Brandon, and Lake Lenore) in 2000. The Watrous trial was lost to hail in late June. Of the 300 early generation lines evaluated in unreplicated tests in 1999, only 14 lines were advanced for replicated testing in 2000. The data is expressed as a % of AC Barrie for yield and the remaining traits are expressed as a deviation from AC Barrie (Table 4). Of the 14 lines that were evaluated in the field, the lines that were not advanced to the final stage of quality evaluation are not included in the table for sake of brevity.

2001:

A 36 entry, 2 replicate trial was grown at six sites (Kernen, Seed Farm, Goodale, Lashburn, Watrous, Lake Lenore, and Brandon) in 2001. The data is expressed as a % of AC Barrie for yield and the remaining traits are expressed as a deviation from AC Barrie (Tables 5 and 6).

2002:

In 2002, 102 HW wheat lines were grown at six locations in replicated trials. One site (Scott) was lost due to drought and sawfly infestation. At this time, we have advanced 24 out of 58 lines from one test for quality analyses. We drew from this group of lines for the 2003 WBWB test.

A 64 entry, 2 replicate trial was grown at six sites (Kernen, Seed Farm, Scott, Watrous, Lake Lenore, and Brandon) in 2002. A second test comprising of 49 entries was grown at the same sites. The data is expressed as a % of AC Barrie for yield and the remaining traits are expressed as a deviation from AC Barrie (Tables 7 and 8). This is the first year that this breeding project has reached a critical mass for potential Coop entries.

In addition to trials HWWYT#1 & 2 we ran two tests (2 reps each) with 64 entries at our Kernen Farm in 2002.

Unlike 2001, we were unsuccessful in obtaining emergency funds for winter increases, thus we did not send extra material for increase for 2003 yield-tests. This will mean that we will be growing fewer sites in 2003 due to seed shortages.

2003:

In 2003, 40 HW wheat lines were grown at four locations (Seed Farm, Kernen, Watrous and Lake Lenore) in replicated trials ($r=2$). The drastically reduced grain yields in 2002 precluded having more test sites in 2003.

We advanced 10 lines (Table 9) that survived the initial stages of quality analyses (Table 10). We drew on this group of lines for the 2004 HW 'B' test.

We tested approximately 1,300 HW lines in unreplicated trials at Kernen in 2003. The yields of the unreplicated tests were markedly improved over the yields obtained in 2002; but still 25% below our long-term average due to drought, grasshopper, and sawfly infestations.

2004:

In 2004, 59 HW wheat lines were grown at six locations (Seed Farm, Kernen, Trochu (AB), Brandon (MB), Watrous and Lake Lenore) in replicated trials ($r=2$).

We advanced 18 lines (Table 11) for quality evaluation and eight of those survived to culling to intermediate level quality tests (Table 12). We will draw on this group of lines for the 2005 HW 'B' or HW 'C' Registration Tests.

We tested approximately 1,800 HW lines in unreplicated trials at Kernen in 2004. The yields of the unreplicated tests were equivalent to 4,500 to 5,000 kg/ha with good differential for lodging, soil nutrient stress and Falling Number values.

C-2. A Grain Pigmentation Test for evaluation of lines in preliminary Yield Tests

Three hundred early generation lines ($n=300$) derived from 31 populations were evaluated in unreplicated tests in 1999. Of the 300 lines, 109 lines (derived from 18 populations) were advanced for pigmentation analysis based on agronomic and protein content data. Whole grain samples of the 109 lines were screened using a Hunterlab colorimeter. A summary of the data is presented Table 13. Hunterlab color L and b values for the populations indicated that the lines varied in kernel brightness. This simple screening test to eliminate lines based on lack of seed brightness (whiteness). This test was subsequently used to evaluate lines in replicated and unreplicated trials during the remainder of this project.

C-3. Early generation breeding materials (1999-2004)

1999 and 2000:

Approximately 900 white-grained F4 and F3 lines were sent for seed multiplication to a winter nursery in 1999. Close to 1900 lines, originating from 51 populations, were entered in a series of unreplicated tests grown at Kernen in 2000. Approximately 1000 lines, originating from 46 populations, were advanced for protein content determinations. Lines advanced based on protein were subsequently evaluated for grain brightness using a colorimeter, with selected lines advancing for replicated testing in 2001. The same selection sequence was adopted for subsequent unreplicated yield trials (2001 to 2004).

Approximately 2,700 F2 and F3 white-seeded lines were screened for sprouting resistance in the fall of 1999 (Table 14). The most dormant lines ($n=705$) were grown in the greenhouse and a pollen sub-sample was used for backcrossing purposes. The resulting F1 progeny were grown in the greenhouse to produce F2 progeny. The F2 progeny were subsequently grown in the field in 2000. These progeny were sent to New Zealand for a generation of advancement and were planted in a rust nursery in 2001. Three of the most promising populations were advanced using single-seed descent in 2000.

Five families were put through the double-haploid program, 285 lines were produced in 1999. Approximately half of the lines ($n=160$) were sent for seed multiplication to a winter nursery (1999). Twenty-four of these lines were subsequently evaluated in unreplicated trials in 2000.

Of the hard white lines evaluated in our 2000 rust nursery, 300 rows were advanced for unreplicated testing in 2001. Approximately 800 white-grained F4 lines were sent for seed multiplication to a winter nursery (2000-2001) and were subsequently advanced for unreplicated testing in 2001.

Approximately 44 new breeding populations were developed over the winter of 1999/2000, with emphasis placed on incorporating dormancy into adapted Canadian cultivars and into our advanced white-grained breeding lines. Twenty-one new breeding populations ($n=21$) were developed over the summer of 2000, with emphasis placed on hybridizing elite white wheat lines with adapted Canadian cultivars and our advanced white-grained breeding lines. Six new breeding populations ($n=6$) were initiated during the fall of 2000, with emphasis on backcrossing dormant F2 lines (Table 16) with adapted Canadian cultivars and into our advanced white-grained breeding lines. The F2 lines, used as donor parents, were grown in the greenhouse to produce seed which was subsequently planted in the field in 2001 in the F3 generation.

2001:

Approximately 800 white-grained F4 lines were sent for seed multiplication to a winter nursery in 2000. In addition, 240 DH lines were increased in a winter nursery. These 1,040 lines were supplemented by 308 F4 and F5 lines selected from our 2000 rust nursery at Saskatoon. Thus, approximately 1,300 lines were evaluated in an unreplicated yield trial format at Saskatoon in 2001. Approximately 800 lines of the lines, originating from 52 populations, were harvested and advanced for protein content and SDS Sedimentation determinations. Of those lines, 326 were subjected to H-Lab brightness determinations. Of the 326 lines, 257 were retained for further quality determinations.

Of the lines derived from crosses made in 1996-1997, 70% were culled due to insufficient seed whiteness. Of the lines derived from crosses made in 1998 and 1999, only 10% were discarded based on H-L measurements. Thus, we were able to improve the over-all seed whiteness of breeding material by judicious use of parental material.

In addition to the DH lines yield-tested in 2001, an additional 218 DH lines were screened in a rust nursery.

One DH population of 152 lines has been developed to study the dormancy present in W98616 (see Section A.8) and to study the inheritance of seed brightness. Most of the lines were grown in the field in 2001 with some being sent for winter increase.

Ninety four F3 and F4 hard white wheat populations were grown in bulk plots in an irrigated rust nursery in 2001. A majority of these populations were designed for incorporating dormancy into adapted Canadian cultivars and into our elite white-grained breeding lines identified in 1999. Twenty-four new breeding populations from crosses made during the summer of 2000 were grown as F2 space-planted bulks in 2001. These 24 populations were advanced in a winter nursery (2001/2002). Fifteen new populations were initiated in 2001.

2002:

Nearly 13,700 F4 to F6 generation lines were tested in our irrigated rust nursery and 48 populations were grown under irrigation in the same nursery. The rust pressure was very high in 2002 resulting in the culling of a high percentage of the breeding lines.

We tested approximately 1,800 HWWS lines in unreplicated trials at Kernen in 2002. Of the 1,800 lines, 160 were DH's. The yields of the unreplicated tests were very low due to drought, grasshopper, weed and sawfly infestations and it is difficult to predict how much effective selection pressure was achieved.

A new series of 460 white-seeded DH lines was increased in the rust nursery or greenhouse during the summer of 2002. An additional 100 white-seeded DH lines were increased in the greenhouse or winter nursery during the winter of 2002-2003.

2003:

Approximately 6,300 F4 to F6 generation lines were tested in our irrigated rust nursery and 28 populations were grown as F2's or F4's under irrigation or in dryland nurseries in 2003. The elevated levels of rust in 2002 resulted in a smaller head-row nurseries in 2003.

Sprouting tests were conducted on F5 lines that survived testing in the 2002 rust nursery. The lines that exhibited some sprouting tolerance were grown in F6 head-rows in 2003 and advanced for unreplicated yield testing in 2004.

Ten new populations were grown as F1's under irrigation in 2003. A further set of new crosses was made during the summer of 2003 and grown as F1's in a winter nursery.

2004:

Approximately 3,300 F5 generation lines were tested in our irrigated rust nursery and 38 populations were grown as F2's or F4's under irrigation or in dryland nurseries in 2004.

Thirty-nine new populations were grown as F1's in the field in 2004. A further set of 15 new crosses was made during the summer of 2004 and grown as F1's in a winter nursery. Five populations were advanced two generations via single seed descent during the winter of 2004-2005.

C.4 W98616 Sprouting resistant hard white wheat germplasm line

Pedigree and Breeding Methods

Line W98616, selected from the cross AUS1408/RL4137, was developed at the Crop Development Centre, Department of Plant Sciences, University of Saskatchewan. AUS 1408 (Mares 1987), a white-seeded wheat, and RL4137 (Noll et al. 1982), a red-seeded wheat, are both considered good sources of preharvest sprouting resistance. RL4137 is the source of elevated sprouting resistance in a number of Western Canadian red spring wheat cultivars (e.g., Columbus). Line W98616 traces its origin to a single F₅ plant. The F₂ to F₅ generations were grown under field conditions and advanced as bulks. In the F₅, single spikes were harvested and selected visually for white grain colour. In the F₆ generation, 213 lines were grown in unreplicated hills and screened against delayed heading and late maturity. Of the 213 hills (lines), 37 lines were selected for seed dormancy evaluation. A sub-sample of each F₆ line was germinated in petri-dishes (5 mL de-ionized water/plate) in darkness at 24°C for one week. Of the 37 lines, 24 lines exhibited seed dormancy equal to that of the red-seeded parent, RL4137. Of the 24 dormant lines, eight were selected and advanced based on white-seed coat color (Lamkin and Miller 1980). The

white-seeded F₇ and F₈ generations were tested at the Kernen Crop Research Farm (KCRF), University of Saskatchewan in an unreplicated trial in 1997 and a two-replication trial in 1998. Selections were made for preharvest sprouting and acceptable maturity in both years. Line W98616 and check cultivars were tested at the University of Saskatchewan using a RCBD with four replications at one location (KCRF) in 1999 and two locations (KCRF and Seed Farm) in 2000.

Performance

Preharvest sprouting tolerance was evaluated by germination tests (Matus-Cádiz et al. 2001) and spike-wetting (Hucl 1994). Both untransformed and transformed (arc sin square root percent) data were analysed using ANOVAs, untransformed data are presented as resulting ANOVAs were similar. In 1999 and 2000, nine weeks of storage at 24°C, prior to germination at 20°C for one week, was unable to completely overcome dormancy in line W98616 (Table 15). Line W98616 has improved seed dormancy compared to white-seeded cultivars and is similar in sprouting resistance to Columbus, a red-seeded sprouting resistant cultivar. In 1998, W98616 had improved sprouting resistance (mean=12%; LSD_{0.05}=20) compared to Katepwa (72%) and similar resistance relative to Columbus (12%). The seed viability of each seed lot, based on nine weeks of storage at 24°C prior to germination at 15°C for two weeks, was high with germination levels ranging from 98 to 100%. The grain yield for line W98616 was lower relative to all check cultivars (Table 16). Test weight, kernel weight, maturity, plant height, grain protein, and kernel hardness for line W98616 were similar to those of Snowbird, a hard white wheat cultivar. The important features of W98616 are the introduction of seed dormancy similar to that of the red-seeded sprouting resistant cultivars, AC Domain and Columbus, and sprouting resistance similar to Columbus. W98616 has significantly stronger seed dormancy than white-seeded cultivars AC Vista and Snowbird.

Seed of W98616 germplasm was registered as CN 19055 with Plant Gene Resources of Canada on 2 March 2001. Small quantities of seed are available from Plant Gene Resources of Canada, Curator of Seed Gene Bank, Saskatoon Research Centre, Agriculture and Agri-Food Canada, 107 Science Place, Saskatoon, SK Canada S7N 0X2.

C.5.1 New sources of improved seed dormancy (AUS lines)

We used two other approaches to develop sprouting tolerant parental material. In the first case, we made backcrosses (2 to 3) to either AUS1293 or AUS1408 which are late-maturing sprouting resistant white accessions. A number of CWRS cultivars were used as the donors for earlier maturity. The back-cross-derived lines underwent selection for maturity and sprouting resistance during the selfing process. The most promising eight lines were evaluated over two years.

Eight experimental lines were characterized for seed dormancy level and pigmentation in 2000-2001 (Table 17) relative to red- and white-grained checks. These lines were obtained from backcrosses to either AUS1293 or AUS1408 which are late-maturing sprouting resistant white wheat lines. A number of CWRS cultivars were used as the donors for earlier maturity. The back-cross-derived lines underwent selection for maturity and sprouting resistance during the selfing process. The most promising eight lines were evaluated over two years.

A 14 entry, four replicate trial was grown at the Seed Farm in 2000 and 2001. The experimental design was an RCBD with four replications. Individual plots consisted of five rows, 3.7-m long and 0.3-m apart.

Plots were sown in early May at a rate of 250 seeds m⁻² on fallow land. Seeds were treated with the systemic fungicide Raxil (Uniroyal Chemical Ltd., Elmira, ON) at the recommended rate. Fertilizer was drilled in with the seed at a rate of 7 kg ha⁻¹ of N and 29 kg ha⁻¹ of P. Weeds were controlled with Buctril-M and Puma Super at recommended rates

Freshly harvested seeds were placed into petri-dishes and stored at 24°C in darkness for one week. Following storage at 24°C, seeds were imbibed using water and incubated at 12 or 20°C (in darkness) for 7d. Counts were taken at 7d. Lower percentage germination was observed at 12 and 20°C for the eight experimental lines compared with dormant red (Columbus) or dormant white (W98616) checks. These results indicate that the dormancy of the eight lines was deeper than in Columbus. Wheat genotypes differed significantly in grain color (NaOH treated). Whole grain samples were treated with 1.25M NaOH for 1 hour at room temperature to differentiate white-seeded genotypes from red-seeded genotypes. For the eight lines, grain lightness (L-value) varied from 24.1 to 26.7 units, redness (a-value) from 6.4 to 7.8 units, yellowness (b-value) from 9.9 to 11.6 units, and total color difference (ΔE) from 3.6 to 6.7 units. White seeded checks (Snowbird, AC Vista, AUS 1293, and W98616) were significantly lighter in grain color relative to the eight lines. Red-seeded checks (Katepwa and Columbus) were similar in grain lightness to 99 AUS 27 and 99 AUS 34. Hence, the remaining six lines were intermediate in grain lightness relative to white- and red-seeded checks. These results indicate that the eight lines are possibly carrying at least one dose of the gene controlling red color in hexaploid wheat. Seed dormancy and pigmentation of 99 AUS 7, 99 AUS 8, and 99 AUS 11 are light-seeded enough to use as parental material in the hard white wheat program. Two entries were crossed with an adapted Canadian hard white wheat cultivar and reached the F4 generation in 2004.

A 16 entry, four replicate trial was grown at the Seed Farm and Kernen in 2002. The experimental protocol was the same as in 2001.

The six experimental lines possessed significantly darker, redder, and less yellow grain color indicating that all lines were red-seeded. For the AUSROW lines, grain lightness (L-value) varied from 22.0 to 23.1 units, redness (a-value) from 8.0 to 8.9 units, yellowness (b-value) from 8.6 to 9.4 units, and total color difference (ΔE) from 7.7 to 9.0 units. White seeded checks (Snowbird, AC Vista, AUS 1293, and W98616) were significantly lighter in grain color compared with the six experimental lines. Katepwa, Columbus, CDC-EMDR-14, and 99AUS-9 possessed significantly darker grain relative to 99AUS-7 and -8. Red-seeded check CDC-EMDR-4 possessed significantly lighter grain and a lower level of seed dormancy at 12°C relative to 99AUS-7 and -8 (Table 18). Red-seeded check Line 211 and CDC-EMDR-9 possessed similar grain lightness and seed dormancy at 12°C compared with 99AUS-7 and -8. Lines 99AUS-7 and 99AUS -8 possessed improved seed dormancy at 12°C and similar sprouting resistance relative to W98616. Percentage germination (12 and 20°C) and sprouting values were highly correlated ($r \geq 0.81^{**}$) indicating that seed dormancy at 20°C was a good indicator of dormancy at 12°C and sprouting resistance (Table 19). Collectively, these results indicate that the six experimental lines are likely carrying one, two, or three doses of the gene controlling red color in hexaploid wheat. In summary, two red-seeded AUS lines (i.e., 99AUS-7 and -8) were determined to possess deeper seed dormancy at 12°C relative to W98616 and similar dormancy compared with Line 211 and CDC-EMDR-9. Lines 99AUS-7 and -8 likely possess one or two genes controlling red-seed coat color indicating that both lines would be useful sources for improving seed dormancy in new white-seeded cultivars.

C.5.2 New sources of improved seed dormancy (X99.65 lines)

In the second approach we crossed W98616 with one of our deeper dormancy red-seeded germplasm releases (Line 211). In 2002, 30 lines (F5 generation) derived from the cross Line 211/W98616 (cross #X99.65) and three check cultivars were characterized for grain color and seed dormancy. The objective was to identify white and red-seeded lines with deeper levels of seed dormancy. White and red-seeded lines were identified with equal to, or deeper, seed dormancy than Line 211. A 33-entry, two replicate trial was grown at the Seed Farm. The three check lines included W98616 (white-seeded and highly dormant), Line 211 (red-seeded and highly dormant), and Katepwa (red-seeded and low-dormancy). Line 211 is a germplasm line that was released by the U of S in 2002. Seed dormancy levels are known to be higher in Line 211 than in W98616 at 12 and 20°C. The experimental design followed that described in Section A5.1

At Zadoks growth stage 92, 40 spikes per plot were harvested from the upper canopies and air-dried at 24°C (40% RH) in darkness for one week. Thirty spikes per plot were bulk threshed using a rubber belt thresher prior to storing cleaned seed samples at -20°C until needed. Ten spikes per plot were threshed using a single head thresher as entries were visually screened for segregating seed color. For grain color determinations, disposable petri dishes (60 x 15-mm) were filled to half their capacity with grain. The grain within each dish was treated with 15-mL of 1.25 mol L⁻¹ NaOH and 0.1% tritonX-100 for 1-hr at 24°C. Excess NaOH solution was removed prior to collecting color values. Color measurements were measured with a Hunterlab color difference meter (Color Quest 45/0, Hunter Associates Laboratory, Reston, VA) as *L*-, *a*-, and *b*-values. Total color difference (ΔE) was calculated as follows: $\Delta E = \text{SQRT}(\Delta L^2 + \Delta a^2 + \Delta b^2)$ where Δ is the difference between W98616 and sample readings. For seed dormancy determinations, germination tests were conducted within four months of harvest. Seeds were considered germinated if the radicle had emerged by 2 mm from the seed coat. Percentage germination data were calculated as follows: (# of germinated seeds/50 imbibed seeds) x 100. Seeds were placed in 8 cm petri-dishes each containing one filter paper (Whatman No.1) and filters were moistened with distilled water (5mL). Seeds were uniformly spaced on the filters so that contact of adjacent seeds was avoided. Petri-dishes were placed in a large plastic container containing water saturated towels before placing into incubators. Two replications of 50 seeds per entry were used. Seeds were incubated in darkness at 12 and 20°C. Counts were at 14 and 21 days. Un-sprouted kernels were treated with a 0.05% GA₃ solution (1-mL/petri-dish) and incubated in darkness at 12°C for 7-d. Based on the one week GA₃ treatment, seed viability of seed lots was deemed acceptable in 2002 and 2003 (germination levels of $\geq 95\%$).

Hunterlab values for whole grain treated with NaOH and percentage germination for the 30 lines derived from cross # X99.65 (F5 generation) and three checks are presented in Table 20. The 30 lines ranged in grain color (*L*=22.3-28.2 units; *a*=6.3-9.3 units; and *b*=8.8-12.6 units). Six lines including X99.65-1, -2, -6, -7, -15, and -28 were selected based on their lighter *L* values and similar seed dormancy at 12°C (2 wks) relative to Line 211. Out of these six lines, only X99.65-28 showed significantly deeper dormancy levels at 12°C compared with Line 211. Germination at 20°C and 12°C after two weeks of testing were moderately correlated ($r=0.70^{**}$) indicating that seed dormancy at 20°C may not be a very good indicator of dormancy at 12°C, in this population (Table 21). Ten spikes per line were visually inspected for grain color. All six lines possessed hard endosperm texture, except for X99.65-1, -6, and -15. Seed from one white-seeded spike per population was increased under greenhouse conditions (winter 2003) for field testing in 2003. Red-seeded lines X99.65-8, -16, -17, and -24 showed significantly deeper dormancy levels at 12°C compared with Line 211.

In 2003, nine lines from Cross #X99.65 and three check cultivars were characterized for grain color and seed dormancy. The nine lines in question were selected from the 30 lines evaluated in 2002. A 12-entry, four replicate trial was grown at the Seed Farm.

Hunterlab values for whole grain treated with NaOH and percentage germination for the nine lines derived from cross # X99.65 and three checks are presented in Table 22. Red-seeded line X99.65-6 showed significantly deeper dormancy levels at 12°C compared with W98616 after 1 week of testing. Of the other eight X99.65 lines, all lines were white-seeded and showed similar dormancy levels at 12°C relative to W98616 after one week of testing. White-seeded lines X99.65-3, 7, and 15 were similar in dormancy levels relative to line 211 when tested at 20°C for one week while the other white-seeded lines were significantly less dormant relative to Line 211.

C.6 Testing of various germination methods to overcome seed dormancy in W98616 and other sprouting resistant CDC germplasm releases

Five dormant spring wheat genotypes (W98616, line 211, CDC EMDR-4, CDC EMDR-9, and CDC EMDR-14) were used in this study. W98616, a white-seeded line, was selected from cross AUS1408/RL4137. Line 211, a red-seeded line, was selected from cross AUS1408/RL4137//AUS1293/Park/3/Ford/Rongotea/Kleiber/Tordo. CDC EMDR 4, a red-seeded line, was selected from cross AUS1293/Park. CDC EMDR-9 and -14, two red-seeded lines, were selected from cross AUS1408/Park. The parents used in each cross are considered good sources of pre-harvest sprouting tolerance (Derera 1989; Hucl 1994). Genotypes possessed conventional plant heights and; thus, were expected to be sensitive to gibberellic acid treatments.

In 2000, W98616, line 211, CDC EMDR lines, Roblin (Canada Western Red Spring, CWRS; Campbell and Czarnecki 1987), AC Domain, Columbus, and RL4137 were grown at the Kerns Crop Research Farm (KCRF) and at the Seed Research Farm (SRF).

Germination tests were conducted within 24 weeks of harvesting and followed standard protocols (CFIA 1997). Spikes were hand-threshed. Cracked or shriveled seeds were discarded. Seeds were placed in 9-cm petri-dishes, each dish containing one filter paper, and moistened with 5-mL of distilled water, unless otherwise specified. Petri-dishes were placed in plastic containers containing water-saturated towels prior to incubating (Hotpack Corp., Philadelphia, PA; Model 352632). Seeds were considered germinated if the radicle had emerged 2-mm from the seed coat. Percentage germination was calculated as follows: (number of germinated seeds/50 imbibed seeds) x 100. Four replications of 50 seeds per genotype were used in each experiment. Three laboratory experiments were conducted. In experiment one, seeds were stored at 24°C (40% relative humidity) for zero, three, six, nine, 12, 15, 18 and 21 weeks. Following storage at 24°C, seeds were imbibed and incubated at 20°C in darkness for 7d. First and final germination counts were taken at 7d. In experiment two, seeds were imbibed and incubated at 5, 10, 15, 20, and 25°C. Counts were taken at 2d-intervals for a period of 14d. Eight dormancy-breaking pre-treatments, including 0.0006 M GA₃ (0.2 g of Sigma G-7645 dissolved in one litre of distilled water), 0.0014 M GA₃ (0.5 g L⁻¹), 0.01 M KNO₃ (1 g of Sigma P-6083 dissolved in one litre of distilled water), 0.02 M KNO₃ (2 g L⁻¹), chilling at 5°C for 5d, chilling with 0.01 M KNO₃, heating at 35°C for 6d, and heating with 0.01 M KNO₃ were tested in experiment three as described by the CFIA (1997). Following treatments, seeds were incubated at 10°C. Counts were taken at 2d-intervals for a period of 14d. For chilling, seeds were imbibed for 24h at 24°C before incubating at 5°C for 5d. For heating, seeds were heated using an Isotemp oven (Fisher Scientific; Model 655G; air was circulated using a portable fan) for 6d before imbibing

seeds. Average moisture content of de-hulled grain samples was 11.1% (SE ± 0.03) before drying and 7.5% ± 0.2 after drying. Chilling or heating periods were not included in the 14d germination period.

For the growth chamber study, the experimental design was a completely randomized design with six replications. Conditions were set to 20°C (day/night) with 18h light and a photosynthetically active radiation level of 250 $\mu\text{mol m}^{-2} \text{s}^{-1}$. One-hundred dormant seeds of uniform size of Roblin, Columbus, and CDC EMDR-9 were treated, as described above, with water, 0.0006 M GA₃, 0.0014 M GA₃, chilling with 0.01 M KNO₃, or heating with 0.01 M KNO₃. The water treatment, or the positive control, was applied to non-dormant seeds. Non-dormant seeds were obtained by storing grain samples at 24°C for 24 weeks. Pre-treated seeds were simultaneously incubated at 10°C for 4d. Seeds were planted if the radicle was five to 10-mm emerged from the seed coat. Ten pre-germinated seeds were planted (2.5-cm depth) per 15-cm diameter pot. Pots were filled with Terra-Lite Redi-Earth (W.R. Grace and Co. of Canada Ltd. Ajax, ON). Seedlings were watered every 4d and fertilized using Type 100 Nutricote controlled release granular fertilizer (14-14-14) (Plant Products Co. Ltd. Brampton, ON) at a rate of 0.8-kg m⁻². When seedlings reached the four-leaf stage (ZGS 14), seedling length (excluding roots), first internode length, and biomass yield measurements were collected on five seedlings per replication (pot). Seedling roots were cut off at the crown. For biomass data, five seedlings per sample were oven-dried at 80°C for 24-h before weighing. The growth chamber experiment was done in duplicate.

Statistical analyses were conducted using Minitab Version 13 (Minitab Inc, State College, PA). Means of percentage germination data were tested to be significantly different ($P=0.05$) from $\geq 5\%$ germination using one-tailed t-tests. Bartlett's test ($P=0.05$) was used to test for homogeneity of variances. Data collected in the repeated growth chamber study were analyzed using one-way ANOVAs.

Dormant genotypes had deeper dormancy levels relative to Roblin, the non-dormant control (Fig. 1). In dormant genotypes, six (AC Domain and Columbus), nine (W98616), 12 (RL4137), 15 (line 211, CDC EMDR-4, and CDC EMDR-14), and 18 (CDC EMDR-9) weeks of storage at 24°C, prior to incubation at 20°C for 7d, were required to overcome seed dormancy ($\geq 5\%$ germination). In contrast, only three weeks of storage was required to obtain $\geq 5\%$ germination in Roblin. In the second experiment, dormant genotypes exhibited high levels of dormancy compared to Roblin at germination temperatures of 5, 15, 20, and 25°C (Fig. 2). Low germination levels ($\leq 0\%$) were detected in the five dormant germplasm lines after 14d of incubation at 20 or 25°C, while Roblin was $\geq 9\%$ germinated. Incubation at 10°C led to $\geq 5\%$ germination in 10d for the three dormant controls, while incubation at 5, 10, 20, and 25°C were ineffective for breaking dormancy. Generally, the highest percentage germination for the five highly dormant germplasm lines was observed at 10°C after 10d of testing (ranging from 51 to 96 % germinated), with reduced germination at 5°C (ranging from 25 to 72 % germinated) and 15°C (ranging from 21 to 82 % germinated). The effectiveness of pre-treatments was tested using an incubation temperature of 10°C (in darkness) for 14d because this temperature regime, compared with using 5, 15, 20, and 25°C, appeared to induce the highest levels of germination in the genotypes tested.

Four pre-treatments including 0.0006 M GA₃, 0.0014 M GA₃, chilling with 0.01 M KNO₃, and heating with 0.01 M KNO₃ led to $\geq 5\%$ germination within 10d of incubating at 10°C (Fig. 3). Roblin reached $\geq 5\%$ germination in the 14d incubation period using all eight pre-treatments. Both GA₃ pre-treatments overcame the seed dormancy in all dormant genotypes within 8d of testing. Chilling or heating pre-treatments alone were effective in overcoming dormancy within 14d of testing only in W98616. Chilling with 0.01 M KNO₃ and heating with 0.01 M KNO₃ overcame the seed dormancy in all dormant genotypes within 10d and 4d of testing, respectively. Using 0.02 M KNO₃ compared with 0.01 M KNO₃ appeared to retard germination in the dormant wheat genotypes. Potassium nitrate, chilling, and heating treatments

alone, compared with combining KNO_3 with chilling or heating, were ineffective in breaking dormancy within the testing period.

Both GA_3 pre-treatments were associated with etiolated seedling growth while other pre-treatments tested were associated with normal early seedling growth (Table 23). In Roblin, Columbus, and CDC-EMDR-9, seedling and first internode lengths were significantly longer using GA_3 treatments compared with distilled water, chilling with 0.01 M KNO_3 , or heating with 0.01 M KNO_3 pre-treatments. Pre-treatment did not affect biomass yield (Table 23)

Generally, dormancy in the mature seed of most modern cultivars of common bread wheat lasts only a few days and is lost before the seed is sown (Simpson 1990). Nevertheless, there are cultivars where seed dormancy can last for several months. Freshly harvested samples of the eight dormant lines exhibited high levels of dormancy that gradually decreased within three (AC Domain, Columbus, W98616, and RL4137) to five months (line 211 and the three CDC EMDR lines) of harvesting (Fig. 1). These germplasm lines appear to be some of the most dormant sources of dormancy reported to date (Hucl 1994). Deeper dormancy in grasses is expressed as a broadening of the range of temperatures, either side of some optimal value, in which germination is inhibited (Simpson 1990). Generally, high percentage germination was observed at 10°C, compared with 5, 10, 20, or 25°C, in the five germplasm lines tested (Fig. 2). Similarly, Mares (1984) reported that the optimum temperature for the complete germination of RL4137, a strongly dormant genotype, was 10°C. Experimental line RL4137 is the source of elevated sprouting tolerance in a number of CWRS wheat cultivars including Columbus (Campbell and Czarnecki 1981) and AC Domain. Consequently, it is not surprising that the pre-determined optimum temperature for RL4137 was effective for completely germinating freshly harvested samples of AC Domain and Columbus. In contrast, incubation at 10°C in darkness for 14d was ineffective in overcoming dormancy in Line 211 and the CDC EMDR lines. The deep dormancy levels in these germplasm lines may result from gene stacking of dormancy genes.

Gibberellic acid can be used to promote germination of dormant seed samples, but is not recommended for overcoming dormancy in wheat (CFIA 1997). Pfahler et al. (1991) reported in their seed-priming study that increased germination percentages were observed in two non-dormant wheat cultivars using 0.0012 and 0.01 M GA_3 , with 0.01 M GA_3 substantially increasing germination percentages compared with zero or 0.0012 M GA_3 . Similarly, in the present study, pre-treating with 0.0014 M GA_3 , compared with 0.0006 M GA_3 , promoted slightly faster germination rates in AC Domain, W98616, and Line 211 (Fig. 3). The germination rate of CDC-EMDR-14 showed little change when using 0.0006 or 0.0014 M GA_3 , indicating that pre-treatments with 0.002 or 0.003 M GA_3 may be needed to affect the rate of germination in this genotype. Unfortunately, the use of these higher rates of GA_3 would be of little use to breeders for overcoming dormancy in their selected lines as GA_3 pre-treatments equal to or greater than 0.0006 M were associated with abnormal seedling growth in the present study (Table 23). Various reports have also associated GA_3 with abnormal or etiolated seedling growth in wheat (O'Brien and Pugsley 1981; Paolillo et al. 1991; Pfahler et al. 1991; Botwright et al. 2001).

Dormancy-breaking pre-treatments such as KNO_3 , chilling, and heating are commonly used to promote germination of dormant seed samples (CFIA 1997). Pre-treating with 0.01 M KNO_3 before incubation at 10°C was effective in overcoming dormancy in all dormant genotypes within 14d, except CDC EMDR-9 (Fig. 3). A 0.02 M KNO_3 pre-treatment is not recommended for use on the dormant genotypes tested because this pre-treatment appeared to slightly retard germination rates. The CFIA suggests using KNO_3 pre-treatments at a concentration of 0.01 or 0.02 M to test dormant seed samples, but cautions testers when using 0.02 M KNO_3 as short roots occur in certain plant species. Similarly, Pfahler et al. (1991)

reported slightly reduced germination percentages for two non-dormant wheat cultivars using a 0.3 M KNO_3 pre-treatment. Chilling or heating pre-treatments alone, before incubation at 10°C, were ineffective in overcoming dormancy in Line 211 and the three CDC EMDR lines within 14d.

Combining pre-chilling or pre-heating with a KNO_3 treatment, relative to using pre-chilling or heating treatments alone, led to higher germination levels in dormant wheat (Fig.3). Pre-chilling combined with 0.01 M KNO_3 , before incubation at 10°C, overcame dormancy in the five germplasm lines within 10d, indicating that this pre-treatment was the second most effective in overcoming dormancy. The improvement in germination rates using chilling combined with 0.01 M KNO_3 compared with 0.01 M KNO_3 alone appears to be explained by the extended germination period. That is, the chilling pre-treatment extended the germination period by 6d as seeds were imbibed for 24h at 24°C before incubating at 5°C for 5d. The ineffectiveness of chilling alone to overcome dormancy in Line 211 and the CDC EMDR lines further indicates that a chilling treatment is of little use other than extending the germination period. Pre-heating combined with 0.01 M KNO_3 , before incubation at 10°C, overcome dormancy in the five germplasm lines within 4d, indicating that this pre-treatment was the most effective in overcoming dormancy. It has been well demonstrated that prolonged desiccation induces loss of dormancy by influencing seed coat structure (Simpson 1990). The ineffectiveness of heating alone to overcome dormancy in Line 211 and the CDC EMDR lines indicates that a heating treatment alone is of little use in overcoming the dormancy in the lines tested unless heating is combined with a 0.01 M KNO_3 treatment.

The use of chilling with 0.01 M KNO_3 or heating with 0.01 M KNO_3 may be of interest to breeders selecting for increased seed dormancy within populations before advancing selected lines in greenhouse grow-outs. This can be accomplished by (1) harvesting single spikes from the upper canopies of a field or greenhouse grown population at ZGS 92, (2) air-drying samples at 24°C for 7d, (3) threshing single spikes, (4) storing them at -20°C until needed, and (5) using only a portion of each sample in germination tests (Hucl and Matus-Cádiz 2002 a, b, c). Samples can be germinated in petri-dishes, containing one filter paper (5 mL de-ionized water per plate), at 22 to 24°C in darkness for 7d. The dormancy of the most promising seed samples can be overcome as follows: (1) remove any excess water from each petri-dish; (2) add one to 1.5-mL of a 0.01 M KNO_3 solution per petri-dish; and (3) incubate at 5°C (in darkness) for 5d followed by an incubation at 10°C (in darkness) for at least 10d. If the reserved or non-hydrated portion of threshed seed samples is used, the dormancy of the most promising seed samples can be overcome as follows: (1) incubate samples at 35°C for 6d; (2) add one to 1.5-mL of a 0.01 M KNO_3 solution per petri-dish; and (3) incubate at 10°C (in darkness) for at least 4d. Pre-germinated seeds can be greenhouse grown in small pots containing a soil mixture. The seedling growth of the most promising lines pre-treated with heating with 0.01 M KNO_3 or chilling with 0.01 M KNO_3 will not be associated with abnormal growth (Table 1). The use of chilling with KNO_3 or heating with KNO_3 will be of particular interest to breeders using backcrossing techniques to improve pre-harvest sprouting tolerance within their programs.

C. 7 Genotype x Environment Interaction for Grain Color in Hard White Spring Wheat

Seventy-nine diverse spring wheat genotypes including 12 check cultivars and 67 white-seeded Australian accessions were used in this study (Table 24). All 79 genotypes possessed a hard endosperm texture, except for the following eight genotypes: 'AC Reed', 'Vectis', 'Tatiara', 'Sunset', 'Katunga', 'Eradu', 'Reeves', and 'Chile Late'. Hard red checks consisted of seven Canadian cultivars from the CWRS class ('Roblin', 'AC Elsa', 'AC Barrie', 'CDC Teal', 'Laura', 'AC Domain', and 'Columbus'). White-seeded check cultivars consisted of four Canadian cultivars ('AC Karma', Canada Prairie Spring [CPS]; 'AC Vista', CPS; AC Snowbird, CWWS; and AC Reed, Soft White Spring) and American cv. 'Argent', a Hard

White Spring wheat. Canadian cultivars were obtained from the Crop Development Centre, University of Saskatchewan, Saskatoon, SK. Argent was obtained from the North Dakota Agricultural Experiment Station, North Dakota State University, Fargo, ND. Australian germplasm lines were obtained from the Australian Winter Cereals Collection, Tamworth, N.S.W.

The 79 wheat genotypes were grown in 2000 and 2001 at the Kernen Crop Research Farm (KCRF) and the Seed Farm (SF). The experimental design was a randomized complete block design with two replications. Individual plots consisted of single rows, 3.6-m long and 0.3-m apart. Plots were sown on 02 May (SF) and 18 May (KCRF) in 2000 and 04 May (SF) and 28 May (KCRF) in 2001 at a rate of 250 seeds m⁻² on fallow land. Data were collected for days to heading, days to maturity, and plant height. Plots were combine-harvested at maturity and grain samples were dried using forced air driers. Plots were harvested immediately after maturity of the latest maturing genotype in an attempt to minimize kernel discoloration caused by weathering. Data were collected on grain yield, test weight, and 1000-kernel weight.

Seed samples were cleaned using a C-XT2 Dockage Tester (Simon-Day Ltd, Winnipeg, MB) before quality and grain color analysis. A 9/64 x 3/4 inch (3.57 x 19.05 mm) rectangular riddle and a 5/64 x 3/4 inch (1.98 x 19.05 mm) rectangular sieve were used to remove shriveled and cracked seed from grain samples. Kernel hardness was determined using a Brabender automatic micro hardness tester (C.W. Brabender Instruments, Inc. South Hackensack, NJ) as described by Miller et al. (1981). Color measurements were measured with a Hunterlab color difference meter (Color Quest 45/0, Hunter Associates Laboratory, Reston, VA) as *L*-, *a*-, and *b*-values. The *L*-value designates the lightness of the sample (100= white and zero= black), *a*-values designate redness when positive or greenness when negative, and *b*-values designate yellowness when positive or blueness when negative. Total color difference (ΔE) was calculated as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where Δ is the difference between AC Snowbird and sample readings. Disposable petri dishes (60 x 15-mm) were filled to half their capacity with about 10-g of grain. The dishes were covered with their corresponding lids before grain color determinations using the colorimeter. For grain samples treated with NaOH, the grain within each dish was treated with 15-mL of 1.25 mol L⁻¹ NaOH for 1-h at 24°C based on the method outlined by Lamkin and Miller (1980). Excess NaOH solution was removed from each dish. Dishes were covered with their corresponding lids before grain color determinations. Grain (30-g) was ground to pass through a 1-mm screen on a cyclone sample mill (Udy, Fort Collins, CO) to produce whole meal. Meal samples were placed into resealable plastic bags (75 x 145-mm) for meal color determinations. Moisture content of meal was based on Method 44-15A (AACC, 1995). Protein (N x 5.7) in meal was based on Method 46-30 using an FP-528 Protein/Nitrogen analyzer (LECO Corp. St. Joseph, MI). Yellow pigment and lutein content in meal were based on Method 14-50 using 85% ethanol instead of water-saturated *n*-butanol as a solvent (McCaig et al., 1992). Yellow pigment and lutein contents ($\mu\text{g g}^{-1}$) were calculated using absorbance values taken at 435 and 449-nm, respectively (Johnston et al., 1980).

Statistical analyses were conducted using Minitab Version 13 (Minitab Inc. State College, PA). For balanced ANOVAs, the statistical model included sources of variation due to year, location, replication within location and year, genotype, and interactions involving year, location and genotype. Year, location, replication and their interactions were regarded as random effects, while genotype was a fixed effect. Bartlett's test ($P=0.05$) was used to test for the homogeneity of variances. The Azallini and Cox test for crossover interactions was used to identify changes in rank order among genotypes at a significance level of $P=0.05$ (Baker, 1988). Crossover G x E interactions were calculated for each quadruple combination of 79 genotypes using genotypic means averaged within years and/or locations.

Pearson correlation coefficients were calculated among agronomic traits, grain protein, kernel grinding time, color values, yellow pigment, and lutein using means averaged over locations and years. Grand means and average differences between years were tested for significance ($P=0.05$) using paired t-tests.

Wheat genotypes differed significantly in grain yield, heading, maturity, plant height, test weight, 1000-kernel weight, grain protein, and kernel grinding time (Table 24). Grand means for agronomic traits of hard red (HR, $n=7$), hard white (HW, $n=64$), and soft white (SW, $n=8$) wheat genotypes indicated that the groups were similar in yield, heading, and test weight. Hard red genotypes were earlier maturing, taller, lower in test weight, and higher in grain protein relative to the HW or SW wheat genotypes. Hard white and SW genotypes were similar in maturity, height, kernel weight, and grain protein. Soft white genotypes possessed significantly longer kernel grinding times relative to the HR and HW genotypes.

Wheat genotypes differed significantly in grain/meal color values and yellow pigment/lutein contents (Table 25). For the 64 HW wheat genotypes, grain L -values varied from 42.5 to 49.0, a -values 7.0 to 8.2, b -values 15.5 to 17.6, and ΔE 0 to 4.3 units. Argent was significantly darker in grain lightness relative to AC Snowbird. AC Snowbird was significantly darker in grain lightness relative to AC Karma, AC Vista, and 35 HW wheat AUS accessions. Of the 60 HW wheat AUS accessions, 'Sunelg' was the darkest in grain color while 'Kiata' was the lightest. Yellow pigment (2.5 to $4.8 \mu\text{g g}^{-1}$) and lutein (1.8 to $3.7 \mu\text{g g}^{-1}$) varied among HW wheat genotypes. 'Angas', 'Schomburgk', 'Cascades', 'Krichauff', 'Beulah', 'BT-Schomburgk', and 'Tern' had significantly higher yellow pigment/lutein contents relative to the HW checks. Grand means for color values of HR, HW, and SW genotypes indicated that the groups had significantly different grain/meal color values, but similar in yellow pigment/lutein contents (Table 25). Soft white samples (without/with NaOH) were the lightest and most yellowish followed by HW samples and then HR samples. Hard white and HR samples (without NaOH) were similar in redness, but less reddish than SW samples. Hard red samples were redder than HW samples only after NaOH treatment. Hard white genotypes turned a creamy-yellow color after NaOH treatment while HR genotypes turned a brownish-orange color. Hard red samples had a larger ΔE with NaOH treatment than without NaOH treatment. Hard white meal samples were intermediate in lightness/redness, and more yellowish compared with HR and SW samples.

Significant genotypic variation existed for colorimetric and pigmentation variables (Table 26). Non-significant genotype $\times$ location ($G \times L$) interactions were observed for grain color (without/with NaOH), meal color, yellow pigment, and lutein. Significant non-crossover genotype $\times$ year ($G \times Y$) interactions for grain L -values, grain color (NaOH treated), meal color, and yellow pigment were caused by changes in the magnitude of the response of genotypes over years (data not shown). Significant $G \times Y$ interactions were detected for grain redness, grain yellowness, and lutein. The Azallini and Cox test detected one significant crossover $G \times Y$ interaction for grain redness (Reeves and Condor), one for grain yellowness ('Houtman' and 'Stiletto'), and 12 for lutein ('Sunset' with 'Dollarbird' and 'Hartog'; 'Camamah' with Chile Late, Dollarbird, Hartog, Kiata, 'Leichhardt', Sunelg, 'Tasman', CDC Teal, AC Reed, and Argent). The relative frequencies of crossover interactions detected for grain redness ($[1 \text{ crossover quadruple}/3081 \text{ possible quadruples}] \times 100 = 0.03\%$), grain yellowness (0.03%), and lutein (0.39%) were less than 0.5% . Significant non-crossover genotype $\times$ location $\times$ year ($G \times L \times Y$) interactions for grain L - and b -values were caused by changes in the magnitude of the response of genotypes across years and locations (data not shown). The ANOVA generally remained unchanged for color variables when the seven red checks were removed from the analysis with the exception that the $G \times L \times Y$ interaction for grain lightness became non-significant (data not shown).

Mean performance of HR, HW, and SW wheat genotypes grown in 2000 and 2001 were compared to determine if years differed in the study (Table 27). Average monthly precipitation during grain filling and

maturation ranged from 82 (July) and 53-mm (August) in 2000 to 48 (July) and 6-mm (August) in 2001. Average precipitation values normally observed are 58 (July) and 37-mm (August), respectively. Thus, seed development and maturation of genotypes in this study occurred under dryer conditions in 2001 relative to 2000. Other monthly weather data were similar for 2000 and 2001 (data not shown). In 2001, lower grain yield, earlier maturities, shorter plant heights, lower kernel weights, and increased grain *a*-values (no NaOH) were observed for HR, HW, and SW genotypes. Higher test weights and increased grain *a*-values (without/with NaOH) were observed for HW and SW genotypes. These results suggest that kernels may tend to be smaller with a redder appearance in dry years.

Correlations among grain protein, kernel grinding time, grain/meal color and yellow pigment/lutein contents were determined for 64 HW genotypes (Table 28). Weak correlations were observed among color variables and grain protein. Weak correlations were observed among color variables and kernel grinding time, except for grain *b*-values (no NaOH) and kernel grinding time ($r=0.74^{**}$). Grain color values (no NaOH) were poor indicators of meal color and yellow pigment/lutein contents. Grain *L*- and *b*-values (no NaOH) were highly correlated ($r=0.87^{**}$). Yellow pigment/lutein contents were poorly correlated with meal yellowness (about $r=0.42^{**}$). Yellow pigment and lutein contents were positively correlated ($r=0.99^{**}$). No correlations were observed among agronomic and color variables (data not shown).

Significant variation existed among the 79 wheat genotypes for agronomic traits, grain protein, grain hardness, and grain color values (without/with NaOH). Hard red, HW, and SW wheat genotypes were similar in grain yield, heading and test weight; however, Canadian HR cultivars were earlier maturing, taller, lower in test weight, and higher in grain protein content. Soft white grain samples were the lightest and most yellowish followed by HW and then HR samples. Caution should be exercised when selecting among HW genotypes because our results suggest that increases in grain *b*-values are associated with decreases in kernel hardness ($r=0.74^{**}$). Similarly, Peterson et al. (2001) cautioned breeders when selecting for increased grain *L*-values in white winter wheat as increased grain lightness was associated with decreased kernel hardness ($r=-0.63^{**}$). Hard red genotypes had a larger ΔE with NaOH than without NaOH, confirming that NaOH treatment of grain samples is a useful method for distinguishing among HR, HW, and SW wheat genotypes. Our results indicate that genetic variation for grain color exists among HW wheat genotypes. Similarly, Wu et al. (1999) reported that significant variation for grain color existed among genotypes of hard white winter wheat. The genetic variation described in our study should be useful in improving the grain lightness of AC Snowbird, a CWS cultivar with intermediate grain lightness. Future research is needed to determine the number of genes, if any, controlling and/or influencing white seed coat color in HW wheat.

High yellow pigment content is viewed with disfavor in wheat required for milling and bread making (Moss, 1967). Weak correlations indicated that selecting for lower grain or meal *b*-values would not select for decreased yellow pigment content among HW wheat genotypes. We recommend the use of yellow pigment extraction, instead of grain or meal *b*-values, when distinguishing the least from the most yellowish meal entries in a breeding population. Specific attention should be given to populations derived from parents possessing high levels of carotenoids (e.g., Angas, Schomburgk, Cascades, Krichauff, Beulah, BT-Schomburgk, and Tern). Further research into that area is needed because the use of pigment extraction will result in an overall decreased efficiency in breeding programs. Parker and Langridge (2000) proposed using a sequence tagged site marker, linked to a major locus controlling flour color, to select breeding lines with low carotenoid levels.

Stability of grain color across locations and years in hard white spring wheat is important to crop improvement programs. Lack of statistically significant $G \times L$ interactions for grain/meal color and

yellow pigment/lutein contents indicated that the ranking of genotypes remained constant across locations. Significant non-crossover $G \times Y$ interactions for grain lightness, grain color (NaOH treated), meal color, and yellow pigment indicated that the ranking of genotypes remained constant across years. The Azallini and Cox test detected only one significant crossover $G \times Y$ interaction for grain redness, one for grain yellowness, and 12 for lutein content, indicating that the ranking of few genotypes changed significantly across years. Significant non-crossover $G \times L \times Y$ interactions for grain L - and b -values were caused by changes in the magnitude of the response of genotypes across years and locations. Based on the environments tested within this study, the performance of genotypes was less consistent across years ($G \times Y$) than across locations ($G \times L$). The relative importance of the $G \times Y$ interaction suggests a need for testing grain color in more years rather than more locations. Similarly, Wu et al. (1999) reported that the ranking of winter wheat genotypes for grain color generally remained stable across environments. Peterson et al. (2001) suggested that environmentally induced variations in grain protein content, hardness, vitreousness, and kernel size and shape might all contribute to variation in visual grain color. Similarly, our results suggest that HW kernels tend to be smaller with a redder appearance in dry years. Genotypic differences in grain lightness are generally stable across environments. Consequently, improvements made in one environment are likely to be expressed in other environments.

C.8 Evaluation of 151 Double haploid lines derived from cross ND690/W98616 (2002-2003)

The objective of this experiment was to characterize 151 DH lines for grain lightness (L value with NaOH treatment) and seed dormancy at 20°C relative to parents ND690 and W98616. ND690 (=Argent) is a white-seeded, non-dormant spring wheat cultivar with unacceptably dark grain color for a white-seeded wheat. This research will allow us to a) identify dormant ($n=7$) and non-dormant ($n=7$) DH lines. These lines will be available, in further studies, to develop molecular markers to indirectly select for dormant genotypes and b) identify dark white-seeded ($n=7$) and light white-seeded ($n=7$) DH lines to develop molecular markers to indirectly select for light white-seeded genotypes.

In 2002 and 2003, 151 double haploid (DH) lines derived from cross ND690/W98616 and four check lines (ND690, W98616, RL4137, AUS1408) were characterized for grain color and seed dormancy.

A 155 entry, two replicate trial was grown at the Seed Farm and Kernen Crop Research Farm in 2002 and 2003. The experimental design was a RCBD with two replications. Individual plots consisted of single rows, 3.7-m long sown 0.3-m apart. Plots were sown on 14 May (Seed Farm) and 29 May (Kernen) in 2002 and 09 May (Seed Farm) and 23 May (Kernen) in 2003 at a rate of 250 seeds m^{-2} on fallow land. Seeds were treated with the systemic fungicide Raxil (Uniroyal Chemical Ltd., Elmira, ON) at the recommended rate. Fertilizer was drilled in with the seed at a rate of 7 kg ha^{-1} of N and 29 kg ha^{-1} of P. Weeds were controlled with Buctril-M and Puma Super at recommended rates.

At Zadoks growth stage 92, 40 spikes per plot were harvested from the upper canopies and air-dried at 24°C (40% RH) in darkness for one week. Spikes were bulk threshed using a rubber belt thresher before storing cleaned seed samples at -20°C until needed. For grain color determinations (without and with NaOH treatment), disposable petri dishes (60 x 15-mm) were filled to half their capacity with grain. The grain within each dish was treated with 15-mL of 1.25 mol L^{-1} NaOH and 0.1% tritonX-100 for 1-hr at 24°C. Excess NaOH solution was removed before collecting color values. Color measurements were made with a Hunterlab color difference meter (Color Quest 45/0, Hunter Associates Laboratory, Reston, VA) as L -, a -, and b -values.

For seed dormancy determinations, germination tests were conducted within two months of harvest. Seeds were considered germinated if the radicle had emerged by 2 mm from the seed coat. Percentage germination data were calculated as follows: (# of germinated seeds/100 imbibed seeds) x 100. Seeds were placed in 8 cm petri-dishes each containing one filter paper (Whatman No.1) and filters were moistened with distilled water (5mL). Seeds were uniformly spaced on the filters so that contact of adjacent seeds was avoided. Petri-dishes were placed in a large plastic container containing water saturated towels before placing into incubators. Two replications of 100 seeds per entry were used. Seeds were incubated in darkness at 20°C. First and final germination counts were taken at 7-d. Un-sprouted kernels were treated with a 0.05% GA₃ solution (1-mL/petri-dish) and incubated in darkness at 12°C for 7-d. Based on the one week GA₃ treatment, seed viability of seed lots was deemed acceptable in 2002 and 2003 (germination levels of $\geq 95\%$).

Statistical analyses were conducted using Minitab Version 13 (Minitab Inc, State College, PA). For balanced ANOVAs, the statistical model included sources of variation due to year, location, replication within location and year, genotype, and interactions involving year, location and genotype. Year, location, replication and their interactions were regarded as random effects, while genotype was a fixed effect. Bartlett's test ($P=0.05$) was used to test for the homogeneity of variances. The Azallini and Cox test for crossover interactions was used to identify changes in rank order among genotypes at a significance level of $P=0.05$ (Baker, 1988). Crossover G x E interactions were calculated for each quadruple combination of 155 genotypes using genotypic means averaged within and across years. Pearson correlation coefficients were calculated among variables using Minitab Version 13. Average differences between years were tested for significance ($P=0.05$) using paired t-tests.

Grain color (L values after NaOH treatment)

Wheat genotypes differed significantly in whole grain color without and with NaOH treatment (Tables 29, 30, and 31). The following results are based on means averaged over locations and years. Without NaOH treatment, grain *L*-values varied from 30.6 to 33.9 (difference=-3.3), *a*-values from 5.5 to 6.4 (diff=-0.9), and *b*-values from 10.0 to 11.4 units (diff=-1.4) for the 151 DH lines. With NaOH treatment, grain *L*-values varied from 26.2 to 30.6 (diff=-4.4), *a*-values from 6.7 to 7.5 (diff=-0.8), and *b*-values from 11.5 to 13.8 units (diff=-2.3) for the 151 DH lines. ND690 was significantly darker than W98616 in grain lightness only after NaOH treatment (ND690=27.9 and W98616=29.6 units; $LSD_{0.05}=1.1$). All genotypes turned a creamy-yellow color after NaOH treatment, except for RL4137, which turned a brownish-orange color. These results suggest that the treatment of whole grain with NaOH allows for a better separation of the 151 DH lines being evaluated in this study. Correlations among variables were determined for the 155 genotypes (Table 32). Weak correlations ($r \leq 0.75$) were observed among most NaOH treated and untreated Hunterlab colorimeter variables, except for *b* values without versus with NaOH ($r=0.80^{**}$) and *L* (with NaOH) versus *b* (with NaOH) values ($r=0.95^{**}$). Only the latter correlation was consistent across 2002 and 2003. The distribution of whole grain *L*, *a*, and *b* values (with and without NaOH) for the 155 lines remained relatively constant across years (Figures 4, 5, and 6). Mean performance of the 151 DH lines grown in 2002 and 2003 were compared to determine if year effects differed (Table 33). In 2003, increased grain lightness, redness, and yellowness (without and with NaOH) were observed for the 151 DH lines. These results are likely explained by the occurrence of kernel discoloration resulting from black point and smudge in 2002.

Significant genotypic variation existed for colorimetric variables (Table 31). Non-significant genotype x location (G x L) interactions were observed for all colorimetric values (without and with

NaOH). A significant, non-crossover genotype $\times$ year (G $\times$ Y) interaction for grain lightness (L value with NaOH) was caused by changes in the magnitude of the response of genotypes over years. Significant crossover G $\times$ Y interactions were detected for a values (without and with NaOH) and b values (without and with NaOH). The Azallini and Cox test detected 216 significant crossover G $\times$ Y interactions for redness (a values without NaOH), 41 for yellowness (b values without NaOH), 121 for redness (a values with NaOH), and 11 for yellowness (b values with NaOH). The relative frequencies of crossover interactions detected for a values without NaOH ([216 crossover quadruples/11935 possible quadruples] $\times$ 100 = 0.02%), b values without NaOH (0.003%), a values with NaOH (0.01%), and b values with NaOH (0.001%) were less than 0.02%. Significant crossover G $\times$ Y interactions for a values (without and with NaOH) and b values (without and with NaOH) indicated that the ranking of genotypes did not remain constant across years. These results indicate that grain L values (with and without NaOH) are more stable across years compared with a and b colorimetric values (with and without NaOH). The selection of seven light and seven dark white-seeded DH lines will be based on L values (with NaOH) as this variable allows for better mean separation compared to L values (without NaOH; Tables 29 and 30) and is more stable across environments relative to a values (with and without NaOH) and b values (with and without NaOH). Based on L values (with NaOH), the following 14 DH lines were selected based on averaged genotypic performance relative to ND690 or W98616. Averaged across years, seven white-seeded DH lines (DH-1, -2, -4, -9, -56, -58, and -75) were consistently dark in grain color (L value with NaOH ≤ 7.5 units) and seven white-seeded DH lines (DH-88, -99, -125, -130, -132, -133, and -138) were consistently light in grain color (L value with NaOH ≥ 80.0 units; $LSD_{0.05}=1.1$ units). These results identified dark ($n=7$) and light grained ($n=7$) white-seeded DH lines for the development of molecular markers to indirectly select for light colored genotypes.

Grain dormancy

Wheat genotypes differed significantly in percentage germination at 20 degrees C (Table 30). The following results are based on means averaged over locations and years. Percentage germination varied from 8 to 97% for the 151 DH lines. W98616 (dormant) and ND690 (non-dormant) parental lines showed expected levels of germination (W98616=4% and ND690=97% germinated; $LSD_{0.05}=22\%$). No significant correlations were observed among color variables and germination at 20 degrees C, indicating that seed color and dormancy traits are likely segregating independently within this population (Table 7). The distribution of percentage germination for the 155 lines appeared to be inconsistent across years (Figure 4). Mean performance of the 151 DH lines grown in 2000 and 2001 were compared to determine if years differed in the study (Table 33). Deeper dormancy levels were observed for the DH population in 2003 relative to 2002.

Significant genotypic variation existed for percentage germination (Table 31). A non-significant genotype $\times$ location (G $\times$ L) interaction and a significant non-crossover genotype $\times$ year (G $\times$ Y) interaction were observed for percentage germination, indicating that the ranking of genotypes remained stable across years. The selection of seven dormant and seven non-dormant DH lines was based on averaged genotypic performance for percentage germination at 20 degrees C relative to ND690 or W98616. Seven DH lines (DH-4, -43, -74, -100, -111, -123, and -132) were consistently dormant ($\leq 9\%$ germinated) and seven DH lines (DH-24, -26, -41, -63, -79, -139, and -151) were consistently non-dormant ($\geq 85\%$ germinated; $LSD_{0.05}=22\%$) across years. We have thus identified dormant ($n=7$) and non-dormant DH lines for the development of molecular markers to indirectly select for seed dormancy. Separate populations will likely have to be developed as grain lightness after NaOH treatment and dormancy do not appear to be co-segregating (Table 32).

Stability of grain color and dormancy across locations and years in hard white spring wheat is important to crop improvement programs. Lack of statistically significant $G \times L$ interactions for grain color (without and with NaOH treatment) and percentage germination indicated that the ranking of genotypes remained constant across locations. Significant non-crossover $G \times Y$ interactions for grain color (without and with NaOH) and percentage germination at 20 degrees C indicated that the ranking of genotypes remained constant across years. The Azallini and Cox test detected significant crossover $G \times Y$ interactions for only a and b values (without and with NaOH), indicating that the ranking of genotypes was more stable across years using L (without and with NaOH) compared with a or b values (without and with NaOH). Based on the environments tested within this study, the performance of genotypes was less consistent across years ($G \times Y$) than across locations ($G \times L$). The relative importance of the $G \times Y$ interaction suggests a need for testing grain redness and yellowness in more years rather than more locations. Genotypic differences in grain lightness and dormancy are stable across environments, indicating that improvements made in one environment are likely to be expressed in other environments.

E. CONCLUSIONS AND RECOMMENDATIONS

Although we tested nearly 300 advanced generation lines of Hard White wheat breeding lines at up to six sites each year over a six year period and entered 14 of those lines in the Registration Testing system we were not able to develop a CWHW variety. The lack of adapted HW parental material necessitated the making of genetically wider crosses and this is likely a contributing factor. However, we did identify lines that have been used as parents in further cycles of population development. At this time (February 2005) there are breeding target recommendations in the works from the CWB and CGC. This may result in a shift in kernel shape requirements for the CWHW class. Other than the KVD issue, the targets we put forth in 1999 are part of the current package of recommended targets.

We demonstrated that the HW germplasm line W98616 exhibits stronger seed dormancy than white-seeded cultivars such as AC Vista and Snowbird. The important features of W98616 are the introduction of seed dormancy similar to that of the red-seeded sprouting resistant cultivars, AC Domain and Columbus, and sprouting resistance similar to Columbus. The lower yield and weaker straw of W98616 will necessitate a number of recurrent selection cycles in order to develop agronomically competitive lines with superior sprouting resistance. Since some of the material we developed has high levels of seed dormancy precluding rapid generation turn-over in the greenhouse, we developed and published a protocol that addresses this issue.

Not all white wheat varieties are created equal when it comes to the degree of grain whiteness. The key question is whether genetics or environment is more important in controlling grain color in white wheat. We found that that genetic variation for grain color exists among HW wheat genotypes. Nearly 60% of the Australian cultivars assessed in one of our studies produced whiter seed than the Canadian check variety, Snowbird. This suggests that we must improve on grain whiteness in Canadian germplasm. The variety ranking for grain color of genotypes remained constant across environments. A majority (77%) of the variation in grain whiteness was due to genotype and less than 10% due to environment, indicating that breeding progress should be possible.

In order for the CWHW class to succeed, high yielding varieties with dual purpose quality properties (bread and yellow alkaline noodle) will need to be developed. This will necessitate critical-mass breeding efforts with added emphasis on sprouting resistance and grain whiteness. The pigments involved in grain darkening need to be characterized in order to develop efficient screening methodologies.

Item (f) Acknowledgements:

Matus-Cádiz MA, Hucl P. 2004. Past, present & future: Maximizing pre-harvest sprouting resistance in wheat. In Proc SK Soil & Crops Workshop, U of S, Feb 19-20, Sask, SK. (Oral presentation)

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Item (i). Administrative and other aspects:

Personnel:

Maria Matus-Cádiz, Research Officer (January 1, 2000 – July 31, 2002) – 100%
 Maria Matus-Cádiz, Research Officer (July 1, 2003 to August 31, 2004) – 100%
 Maria Matus-Cádiz, Research Officer (September 1, 2004 to January 31, 2005) – 25%

Nai-Yee Jay, Technician (Oct. 15 – April 30, 2003) – 100%

Madje Cardenas, Technician (April 1 to December 31, 2003) – 100%
 Madje Cardenas, Technician (January 1 to August 31, 2004) – 50%
 Madje Cardenas, Technician (December 1, 2004 to January 31, 2005) – 75%

Mike Grieman, Technician (September 1 to December 31, 2003) – 100%
 Mike Grieman, Technician (September 1 to May 30, 2004) – 100%
 Mike Grieman, Technician (December 1, 2004 to January 31, 2005) – 100%
 Harv Braitenbach, Technician (December 1, 2004 to January 31, 2005) – 100%

Erin Drews, Summer Student (April 15 – October 6, 2000) – 100%
 Amanda Ziegler, Summer Assistant (May 1, 2002- August 31, 2002) – 100%
 Morgan Sather, Summer Assistant (May 1 to August 31, 2003) – 100%
 Morgan Sather, Summer Assistant (May 1 to August 31, 2004) – 100%

Erin Drews, Tech. Assistant (January 1 to April 30, 2003) – 100%
 Russell Lawrie, Tech. Assistant (March 15 to April 30, 2003) – 100%
 A. Eichendorf, Tech. Assistant (January 1 to April 30, 2005) – 100%
 J. Vanes, Tech. Assistant (September 1 to October 30, 2005) – 100%

Other contributors:

Pierre Hucl, Research Professor (January 1, 2000 – February 10, 2005) – 6%
 Connie Perron, Research Officer (January 1, 2000 – February 10, 2005) – 5%

Maria Matus-Cádiz, Research Officer (August 1-July 31, 2002)- 50%
Maria Matus-Cádiz, Research Officer (January 1-July 31, 2003)- 100%

Kenneth Jackle, Technician (January 1, 2000 – February 10, 2005)- 10%

Table 1 Agronomic performance data for the 1999 Hard White Wheat Yield Test.

Treatment	Grain yield (%)	DSE (d)	DPM (d)	Height (cm)	Lodging (1-9)	Leaf blight (0-9)	Test weight (kg/hl)	Kernel weight (mg)
AC Barrie	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Laura	101.3	0.8	0.8	-1.5	1.7	-1.0	-1.4	-3.3
Elsa	105.9	-0.2	-1.4	-2.2	0.4	-1.0	0.0	-2.7
Argent	105.8	-1.8	-0.2	-10.7	0.1	0.1	1.8	7.0
AC Vista	131.4	-1.4	-1.8	-11.7	0.5	-0.5	-1.2	6.7
SWP98105 2	114.8	-2.0	-2.3	4.0	0.1	-1.0	1.4	3.1
SWP98105 3	116.3	-1.6	-1.5	6.0	0.5	-1.1	1.0	1.4
SWP98105 4	116.7	-1.9	-1.9	1.4	0.1	-1.0	2.3	2.6
SWP98105 5	115.9	-1.6	-0.9	3.6	0.1	-0.9	2.2	2.5
SWP98106 1	103.9	-3.7	-3.0	-2.1	1.0	0.0	-1.7	4.6
SWP98112 9	108.9	1.7	2.5	-6.8	0.2	-1.0	-1.8	-0.5
SWP99860 0	103.2	-1.1	-1.5	1.5	0.2	-0.5	0.0	1.2
Pristine	103.7	-3.5	0.2	-15.9	0.2	1.0	0.8	10.6
N	5	4	4	4	4	1	4	4

DSE=Days to spike emergence.

DPM=Days to physiological maturity.

Table 2 Quality evaluation for selected 1999 hard white wheat yield test entries.

Treatment	Flour yield (%)	Protein content (%)	SED (mL)	Falling number (s)	Mixograph				Band width (6 min.)
					Peak time (min)	Peak height (min)	Slope after peak	Mixogram area	
AC Barrie	0.0	0.0	0.0	0	0.0	0.0	0.0	0	0.0
Laura	-1.6	-0.9	7.0	-33	0.3	0.4	-1.5	-3	-9.1
Elsa	-2.3	-0.7	5.0	-26	-0.2	0.5	-1.3	5	-7.4
Argent	-2.7	0.1	9.0	-118	-0.1	-0.1	1.1	8	-2.1
AC Vista	-4.4	-1.4	-4.0	-74	0.3	-3.2	-2.0	-16	-2.8
SWP9810 52	-2.6	-1.0	6.0	-126	-0.3	0.8	0.0	12	-0.6
SWP9810 53	-2.4	-0.9	8.0	-111	-0.3	1.6	-0.7	11	-1.1

SWP9810 54	-2.0	-0.9	7.0	-53	-0.2	0.3	-0.9	4	0.5
SWP9810 55	-2.3	-1.0	3.0	-99	0.1	-2.6	-1.4	-23	0.6
SWP9810 61	-2.9	0.4	3.5	-61	0.0	8.6	-1.6	42	4.7
SWP9811 29	-2.0	-1.2	10.0	-38	0.6	1.0	1.8	-9	-0.3
SWP9986 00	-0.9	-0.5	16.0	-48	1.1	-3.1	1.2	-17	0.6
Pristine	-1.0	-1.4	11.0	-184	1.8	-7.7	0.5	-58	0.4
N	1	6	1	1	1	1	1	1	1

Table 2 Continued.

Treatme nt	Ash conten t (%)	Wet gluten conten t (%)	CSPM T (min)	Loaf volume (cc ²)	Farinograph		Mixing tolerance index (BU)	Amylogra ph peak viscosity (BU)
					Water absorpti on (%)	Developme nt time (min)		
AC Barrie	0.00	0.0	0.0	0	0.0	0.0	0	0
Laura	-0.05	-3.1	0.2	-5	-0.2	1.0	-25	-85
Elsa	-0.03	0.9	-0.4	25	1.0	1.0	-25	-45
Argent	-0.08	-0.4	0.8	5	3.2	1.5	0	-140
AC Vista	-0.08	-8.5	-1.4	-65	0.8	-1.0	10	50
SWP981 052	-0.05	-1.3	0.6	0	0.4	0.5	0	-165
SWP981 053	-0.09	0.9	0.3	50	1.0	1.0	-10	-120
SWP981 054	-0.10	1.4	1.4	35	0.6	1.5	-5	-205
SWP981 055	-0.10	-1.7	1.4	25	0.6	0.0	5	-325

SWP981 061	-0.07	0.9	3.6	15	5.4	3.0	-20	-130
SWP981 129	-0.10	-6.4	2.6	-50	2.2	2.0	-10	-145
SWP998 600	-0.10	-4.8	3.7	-60	-1.0	4.0	-30	-35
Pristine	-0.11	-8.9	3.8	-75	-3.2	3.0	-20	-415
N	1	1	1	1	1	1	1	1

SED=Sedimentation.

CSPMT= Canada Short Process mixing time (dough).

Table 3 Pigmentation and polyphenol oxidase (PPO) evaluation of 1999 hard white wheat yield test samples.

Treatment	Grain color	Hunterlab color values						Carotenoids (ppm)	Free-Lutein (ppm)	PPO (Abs)
		-----Whole grain-----			-----Whole meal-----					
		L	a	b	L	a	b			
AC Barrie	Red	42.5	7.3	13.7	79.5	2.4	11.0	2.9	2.0	0.36
Laura	Red	41.0	7.1	13.9	79.4	2.3	10.5	2.8	1.9	0.25
Elsa	Red	41.7	7.2	14.0	79.1	2.4	10.7	2.7	2.0	0.32
Argent	White	42.4	7.2	14.6	80.3	2.1	10.9	2.7	1.8	0.39
AC Vista	White	45.4	7.1	15.6	80.6	2.1	11.6	3.1	2.1	0.45
SWP9810 52	White	44.8	7.7	16.0	81.9	1.9	10.7	2.4	1.5	0.36
SWP9810 53	White	44.3	7.7	15.6	81.9	1.9	10.6	2.6	1.8	0.39
SWP9810 54	White	44.4	7.7	15.8	81.9	1.9	10.6	2.6	1.6	0.39
SWP9810 55	White	44.2	7.7	15.7	81.8	1.9	10.8	2.7	1.7	0.41
SWP9810 61	White	44.5	7.1	15.2	81.0	2.0	11.1	2.5	1.7	0.37
SWP9811 29	White	44.8	7.0	15.5	81.1	2.0	11.0	3.0	2.0	0.34
SWP9986 00	White	45.7	7.2	15.8	82.4	1.8	10.9	2.9	1.9	0.35
Pristine	White	44.1	7.0	15.4	81.6	1.8	10.2	2.6	1.8	0.40
N	N	1	1	1	1	1	1	1	1	1

Grain color based on 5% NaOH test.

Hunterlab color values: 'L' = 0 (black) to 100 (white); 'a' = +a (red) or -a (green); 'b' = +b (yellow) or -b (blue).

Carotenoid values based on AACC method 14-50.

Polyphenol oxidase assay absorbance values were measured at 405 nm.

Table 4. Agronomic performance of selected 2000 hard white wheat yield test entries.

Entry	Grain yield (%)	DSE (d)	DPM (d)	Height (cm)	Lodging (1-9)	Leaf blight (0-9)	Test weight (kg/hl)	Kernel weight (mg)
AC Barrie	100.0	0.0	0.0	0.0	0	0.0	0.0	0.0
Laura	102.1	0.0	1.4	3.8	0	1.5	-0.7	-0.3
AC Elsa	107.1	-0.2	0.2	-0.3	-1	0.8	-1.6	0.5
Argent	102.4	-1.8	0.7	-6.8	0	0.0	0.3	0.8
Snowbird	101.8	-1.4	0.1	3.5	1	0.2	-0.7	-1.0
4	103.5	-2.3	-0.9	-10.3	0	1.0	-2.8	2.5
5	118.1	-0.4	1.6	-5.0	0	0.3	-1.4	4.5
7	115.0	0.9	3.4	-1.9	1	0.7	-2.2	2.2
9	100.6	-0.8	1.0	-3.4	0	0.0	-0.9	-0.7
10	103.8	-0.5	2.2	-4.4	1	0.3	-1.3	-1.4
11	109.6	-0.2	2.8	-5.3	0	0.2	-0.6	1.8
13	113.8	-2.1	0.4	0.1	0	0.5	-1.8	1.4
14	108.9	-1.5	0.1	3.8	-1	1.0	-1.7	0.1
N	6	5	5	5	1	3	5	5

DSE=Days to spike emergence.

DPM=Days to physiological maturity.

Table 5. Agronomic performance of 2001 Hard White wheat yield test entries

ENTR	ID	NAME	Yield	Head	Matu	Hei	T. K.wt	Bunt	Lf Strs
Y					rity	gh	wt		rst t
	# of Trials		7	6	5	6	7	7	
1	AC Barrie		100.0	-0.0	0.0	0.0	0.0	0	R-
2	Laura		103.4	0.8	0.8	1.4	0.9	0.6	30 R-
3	AC Elsa		102.5	0.7	0.8	4.1	1.0	1.9	-10 MR
4	Roblin		90.9	-2.0	-1.0	1.9	-1.8	0.0	6 MR

5	Snowbird		101.1	-0.2	-0.1	4.5	0.6	0.0	-34	MR	MS
6	HW01001	690*2/W98616	109.7	-1.1	0.8	-2.4	1.2	5.5	-7	R-	
7	HW01002	690*2/W98616	109.4	1.2	2.2	-2.4	1.2	4.6	-18	R	
11	HW01006	Argent/BW204	100.8	-0.4	-0.7	0.9	0.9	4.0	-7	MR	
12	HW01007	Argent//Pasqua/Janz	111.2	3.1	2.5	0.9	1.9	3.4	2	R	
13	HW01008	Argent//Pasqua/Janz	113.6	2.9	2.1	-2.1	1.3	2.5	22	R	
14	HW01009	Argent//Pasqua/Janz	105.1	0.9	0.9	4.2	1.2	1.6	0	R	
16	HW01011	661/3/Arg//395/Batavia	101.8	-0.0	1.0	-2.6	1.6	-0.1	6	R-	
18	HW01013	Argent/BW204	108.1	0.1	1.4	1.3	1.2	3.5	2	MR	
21	HW01016	Argent//Pasqua/Janz	108.4	-0.3	0.9	-1.1	0.5	5.7	-16	R-	
22	HW01017	Argent//Pasqua/Janz	99.0	2.0	1.2	-4.3	-0.5	2.4	3	R	
23	HW01018	Argent//Pasqua/Janz	109.4	1.3	1.2	-4.9	1.4	2.3	-24	R-	
26	HW01021	Argent//Pasqua/Janz	105.4	3.0	3.8	0.7	1.3	3.4	-28	R	
28	HW01023	Argent//Pasqua/Janz	102.4	1.7	2.1	-0.9	0.3	1.9	-11	R	
29	HW01024	unknown	100.1	-0.5	-0.0	-0.5	0.6	5.7	-70	R	
30	HW01025	unknown	102.1	-1.8	0.9	-1.3	0.8	8.9	-57	R	
31	HW01026	Argent//HY438/HY441	102.0	-1.0	-1.0	-3.0	1.3	4.7	-51	MR	
33	HW01028	Argent//HY441/BW689	117.4	1.3	1.6	2.7	2	0.7	-70	R	
34	HW01029	Argent//HY441/BW689	104.1	-2.2	0.4	0.8	2.4	9.9	-19	R-	
35	HW01030	Argent//HY441/BW689	112.5	-1.0	1.0	2.5	2.6	7.4	-8	R-	
36	HW01031	Argent//HY441/BW689	108.3	-0.3	0.6	-0.5	2.8	2.3	-10	R	

Table 6. Quality data for selected 2001 hard white wheat yield test entries.

ENTR Y	ID	NAME	NIR	Leco	SED	FN	FY	ash
			Gpro %	Gpro %	cc	sec	%	%
1	AC Barrie		0.0	0.0	0.0	0	0.0	0.00
2	Laura		0.2	-0.2	6.5	-42	0.5	0.00
3	AC Elsa		-0.2	-0.7	1.0	-34	2.3	0.02
4	Roblin		-0.1	-0.1	12.5	-54	0.2	-0.03
5	Snowbird		-0.6	-0.9	6.5	-46	-0.7	-0.01
6	HW01001	690*2/W98616	-0.5	-0.9	10.5	-54	-2.5	-0.03
11	HW01006	Argent/BW204	0.6	0.2	4.5	-58	-0.9	0.01
12	HW01007	Argent//Pasqua/Janz	-0.8	-0.9	7.5	-67	-3.3	-0.05
16	HW01011	661/3/Arg//395/Batavia	-0.2	-0.8	13.5	-74	-2.0	0.00
22	HW01017	Argent//Pasqua/Janz	0.0	-0.6	3.5	-16	-2.2	-0.02
34	HW01029	Argent//HY441/BW689	-0.8	-0.5	5.5	-18	-2.2	0.01

N =

7

C

C

C

C

C

Gpro = Grain Protein, SED = SDS Sedimentation, FN = Falling Number, FY = Flour Yield, C = grain composite

Table 7. Agronomic performance of selected hard white wheat yield test entries (YT#1) in 2002

ENTR Y	ID	PEDIGREE	GY	DSE	DPM	HT	LDG
1	AC Barrie		100.0	-0.0	-0.0	0.0	-0.0
2	Superb		114.0	-0.9	-1.2	4.1	1.0
3	AC Elsa		107.4	-0.4	-1.0	3.4	0.3
4	AC Splendor		104.5	-3.6	-7.3	8.3	2.1
5	Snowbird		115.2	-1.4	-2.1	10.4	1.6
6	CDC Bounty		114.1	-0.9	-2.8	7.5	1.4
10	HW02004	148/438	110.0	-1.3	-1.3	-3.3	0.4
12	HW02006	Argent//661*2/Vista	109.1	-0.8	-4.0	3.4	0.8
14	HW02008	Argent//438/441	106.0	-0.4	-0.7	0.5	0.5
17	HW02011	264/SWP3	123.9	1.5	2.6	11.4	-0.0
18	HW02012	ND690/X98.107	123.1	-1.5	-1.3	3.7	0.5
19	HW02013	ND690/X98.107	115.0	-1.6	-1.4	5.1	1.1
21	HW02015	ND690/X98.107	105.4	-1.4	-0.7	3.2	0.3
22	HW02016	BW264/X98.116	105.4	-0.4	0.8	4.3	0.9
25	HW02019	ND690//BW749/BW 191	109.5	-2.9	-2.0	9.2	1.1
26	HW02020	ND690//BW749/BW 191	112.3	-0.3	1.3	4.2	0.6
28	HW02022	BW685/Argent	104.3	-4.7	-5.2	9.6	2.0
31	HW02025	BW264/ND690	129.4	1.3	0.8	16.2	0.6
32	HW02026	BW264/ND690	113.9	-1.2	-2.8	3.3	0.6
33	HW02027	BW264/ND690	119.9	-0.0	0.4	6.3	0.5
37	HW01006	Argent/BW204	110.5	-0.9	-1.4	7.1	0.7
41	HW02035	BW264/ND690	108.8	-3.5	-3.8	3.4	1.2
45	HW02039	BW264/ND690	115.1	-1.6	-0.5	9.5	0.8
48	HW02042	BW264/ND690	106.0	0.4	-0.6	-1.0	0.4
50	HW02044	BW264/ND690	110.3	-0.1	-0.1	8.4	0.9
55	HW02049	BW264/ND690	113.5	0.3	1.0	14.7	0.6
58	HW02052	BW264/ND690	103.6	-3.1	-5.6	4.2	0.6
60	HW02054	BW264/ND690	123.6	0.1	1.3	14.6	1.0
61	HW02055	BW264/ND690	112.4	-1.8	0.2	8.1	0.7
63	HW02057	BW264/ND690	105.6	-1.1	-1.8	12.5	1.7
2002	HWWYT#1	N=	5	3	3	2	2

Table 8. Agronomic performance of selected hard white wheat yield test entries (YT#2) in 2002

ENTR Y	ID	PEDIGREE	GY	DSE	DPM	HT	LDG
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1	AC Barrie		100.0	0.0	0.0	0.0	0.0
2	Superb		103.7	-0.5	1.5	0.1	0.2
3	AC Elsa		93.1	-0.5	-0.1	-5.4	0.1
4	AC Splendor		88.0	-4.1	-1.7	-4.2	1.3
5	Snowbird		105.4	-0.7	-0.1	0.3	-0.2
6	HW02059	BW264/ND690	99.2	-2.2	-2.2	-2.9	0.7
7	HW02060	BW264/ND690	113.3	-0.7	0.3	-1.3	0.2
8	HW02061	BW264/ND690	109.9	-0.7	1.4	0.0	0.6
9	HW02062	BW264/ND690	95.7	-2.2	-1.8	-8.3	0.6
10	HW02063	BW264/ND690	103.0	-0.7	-0.3	-3.6	0.8
11	HW02064	BW264/ND690	96.1	-3.0	0.7	-5.2	0.3
12	HW02065	BW264/ND690	105.8	0.6	2.9	0.7	1.1
13	HW02066	BW264/ND690	97.5	-3.0	-1.9	-7.2	1.2
15	HW02068	BW264/ND690	114.8	0.1	0.8	-1.4	0.0
16	HW02069	BW264/ND690	104.9	-1.9	-0.0	-3.9	1.2
17	HW02070	BW264/ND690	108.0	-2.5	0.6	-1.3	0.9
18	HW02071	BW264/ND690	110.1	-0.8	2.1	0.3	0.8
19	HW02072	BW264/ND690	118.4	-1.4	0.2	2.7	0.4
20	HW02073	BW264/ND690	120.3	0.4	1.9	-1.6	0.0
21	HW02074	BW264/ND690	96.1	-3.4	0.7	0.4	0.2
22	HW02075	BW264/ND690	99.7	-2.8	0.1	-7.0	0.2
23	HW02076	BW264/ND690	108.9	-2.5	-0.7	-5.2	0.9
25	HW02078	BW264/ND690	98.1	-3.4	-1.5	-8.7	2.2
26	HW02079	BW264/ND690	102.9	-3.5	-0.4	-4.2	0.6
29	HW02082	BW264/ND690	109.0	-0.1	2.3	4.4	-0.0
30	HW02083	BW264/ND690	95.4	-0.6	-1.0	-1.0	0.1
33	HW02086	ND690/BZ	93.9	-3.7	-1.3	-3.7	2.1
35	HW02088	ND690/BZ	98.2	-1.3	0.4	-6.6	2.2
37	HW02090	ND690/BZ	99.8	-4.4	-0.6	-1.1	1.7
44	HW02097	ND690*2/BW6 85	103.5	-1.1	1.7	-0.9	0.3
46	HW02099	ND690*2/BW6 85	97.6	-3.1	-0.6	-4.0	0.1
47	HW02100	ND690*2/BW6 85	94.8	-3.4	-3.2	1.3	1.4
48	HW02101	ND690*2/BW6 85	105.0	0.1	1.8	2.1	0.7
49	HW02102	ND690*2/BW6 85	118.5	-1.3	0.9	1.5	0.9
2002	HWWYT#2	N =	5	3	3	2	2

Table 9. Agronomic performance of selected hard white wheat yield test entries in 2003

ENTR Y	NAME	03 HWWYT	GY	DSE	DPM	HT	TW T	KW T	SA W	BNT
1	AC Barrie		100.0	0.0	0.0	-0.0	0.0	0.0	0	0
2	Superb		109.6	-2.1	0.0	0.2	0.7	3.9	2	-21
3	AC Elsa		104.3	-0.5	-1.0	4.8	-1.1	-2.8	0	-27

4	AC		93.0	-3.8	-3.3	-1.2	-1.0	0.9	1	24
	Splendor									
5	Snowbird		99.2	-1.0	-0.8	2.7	0.4	-1.3	0	-39
6	W02504	SWP981-009/SWP981-115	106.2	-2.0	1.0	-3.7	-0.1	1.4	0	-8
8	W02540	SWP981-009/SWP981-115	105.6	-1.6	0.8	-2.0	1.1	2.8	0	-17
9	W02547	SWP981-009/SWP981-115	103.2	0.1	0.5	1.3	0.5	4.0	0	-18
11	W02555	SWP981-009/SWP981-115	106.7	-1.9	0.1	-0.3	1.6	5.0	1	38
12	W02566	SWP981-111/SWP981-009	103.6	-3.5	0.4	2.5	1.5	4.8	0	21
18	HW03003	BW264/SWP1	101.7	-2.4	-1.4	2.8	-0.7	-0.9	2	18
21	HW03006	BW264/SWP3	99.3	-2.5	-1.1	5.2	1.2	3.5	1	-25
22	HW03007	BW264//ND690*2/BW685	112.8	-0.4	-1.0	3.8	0.3	1.8	0	-18
26	HW03011	SWP981053//BW264/X98.1	102.2	-1.5	-0.6	1.0	-0.3	-4.3	0	-12
		07								
30	HW03015	BW264//SWP981052/Wilgo	102.7	-1.1	-0.6	-4.5	-0.5	-3.4	0	33
		yne								
		# of sites	4	4	4	4	4	4		

Table 10. Preliminary quality analyses of 2003 HWSW lines.

ENTRY	NAME	03 HWWYT	NIR pro (%)	Leco Pro	SED	FN	FY	Ash (%)	Fpro
1	AC Barrie		0.0	0.0	0.0	0	0.0	0.00	0.0
2	Superb		-0.1	-0.1	5.0	-32	-0.9	0.00	-0.3
3	AC Elsa		0.0	0.0	4.0	30	1.4	0.00	-0.2
4	AC Splendor		0.5	0.5	5.0	-58	-1.9	0.00	0.0
5	Snowbird		-1.0	-1.3	2.5	-2	-1.4	0.00	-0.9
6	W02504	SWP981-009/SWP981-115	0.2	-0.4	5.0	54	-0.1	0.02	-0.8
8	W02540	SWP981-009/SWP981-115	0.1	0.2	-3.0	-34	0.8	0.00	-0.2
9	W02547	SWP981-009/SWP981-115	0.9	0.5	-1.5	23	-0.9	0.01	0.3
11	W02555	SWP981-009/SWP981-115	-0.9	-1.0	-1.0	-79	-0.5	-0.04	-1.0
12	W02566	SWP981-111/SWP981-009	0.7	-0.1	1.0	-81	-1.6	0.03	0.3
18	HW03003	BW264/SWP1	-0.6	-0.9	3.0	-55	0.1	-0.04	-0.6
21	HW03006	BW264/SWP3	-0.5	-0.7	-2.0	-77	0.4	0.03	-0.8
22	HW03007	BW264//ND690*2/BW685	-0.7	-0.4	8.5	-26	-2.3	-0.02	-0.4
26	HW03011	SWP981053//BW264/X98.1	-0.6	-1.3	15.5	-8	-0.5	-0.06	-1.2
		07							
30	HW03015	BW264//SWP981052/Wilgo	-1.1	-1.6	7.5	-91	-1.0	-0.03	-1.4
		yne							
		# of sites	4	C	C	C	C	C	C

SED = SDS sedimentation volume (cc); FN = Falling number (sec); FY = flour yield (%); Fpro=flour protein (%). C = from a grain composite across sites.

Table 11. Agronomic performance of selected hard white wheat yield test entries in 2004

ENT RY	NAME	PEDIGREE	GY	DS E	DP M	ht	LD G	tw t	k wt	LB L	strpr st	B nt	lr
	AC		100					0.	0.				
1	Barrie		.0	0.0	0.0	0.0	0.0	0	0	0.0	0	0	MR
	Superb		112	-				0.	5.			-	
2	AC Elsa		.5	0.8	1.5	-3.5	-0.5	8	9	2.0	0	44	MR
			96.					0.	0.			-	
3	AC		9	0.2	-0.3	0.1	0.2	6	5	0.0	-1	20	MR
	Splendor		95.	-				0.	4.				MR-
4			0	2.8	-4.0	2.8	-0.6	4	5	0.8	-2	6	MS
	Snowbird		100	-				0.	2.			-	MR-
5			.9	0.5	-0.8	4.5	-0.6	3	4	1.5	-2	28	MS
								-	-				
6	W03253	HW00009/BW2 75	101					0.	0.				
			.7	0.3	0.5	-9.1	0.4	3	2	1.5	-2	14	MR
			105					1.	1.			-	
9	HW04003	BW264/ND690	.5	0.3	1.7	-0.9	-1.1	8	5	0.5	-2	54	MR
			106					0.	1.				
10	HW04004	BW264/ND690	.6	0.3	0.7	-7.4	-1.3	7	8	1.8	-1	28	R-
		SWP981-	115					0.	1.			-	
13	HW04007	009/981-115	.5	0.7	1.2	-8.0	-2.1	7	0	1.3	0	28	R-
								-	-				
14	HW04008	SWP981- 009/981-115	109	-		10.		1.	3.				
			.3	0.2	1.5	1	-2.3	2	5	1.0	-2	38	R
		SWP981-	105	-				0.	3.				
15	HW04009	009/981-115	.2	1.1	0.3	-9.9	-0.8	1	4	0.5	3	28	R-
		SWP981-	111					1.	0.				
16	HW04010	009/981-115	.2	0.4	1.5	-9.2	-1.1	1	8	2.3	1	12	R-
								-	-				
18	HW04012	SWP981- 111/981-009	115			11.		0.	3.			-	
			.9	1.1	1.3	7	-1.3	9	4	2.0	-1	30	R-
		SWP981-	116					1.	3.			-	
19	HW04013	111/981-009	.0	1.0	0.4	-9.6	-1.1	0	3	2.8	-1	28	R-
		BW264*2/SWP	103	-				0.	1.			-	MR-
25	HW04019	1	.1	0.9	-1.9	3.2	0.2	9	2	1.2	-2	24	MS
		BW264*2/SWP	103	-				1.	2.			-	
26	HW04020	1	.6	1.5	-2.3	5.0	-1.1	1	2	1.0	0	34	MR
								-	-				
34	HW04028	ND690/X98.29	107	-		10.		1.	5.				
			.3	1.5	0.5	6	-0.5	0	5	0.5	-2	16	R-
			113					0.	2.				
44	HW04038	ND690/X98.31	.3	0.9	2.7	5.8	-0.8	3	5	0.4	-1	2	R-
			119					-	0.				MR-
45	HW04039	ND690/X98.31	.2	1.4	2.8	-5.3	-0.5	1.	0	0.0	1	0	MS

			114					4						
								0.	2.					
46	HW04040	ND690/X98.31	.3	0.0	1.6	-5.5	-1.3	0	1	1.7	-2	20	MR	
								-						
			112	-				0.	5.	-				
51	HW04045	ND690/X98.31	.9	0.1	1.6	-2.6	-0.8	3	7	0.7	-2	12	R-	
								-						
			112	-		16.		1.	0.			-		
52	HW04046	ND690/X98.107	.8	1.2	-0.3	3	-2.3	3	3	1.5	-1	12	MR	
								-						
			107	-				1.	5.					
55	HW04049	ND690/X98.116	.1	0.4	1.6	-7.5	-1.3	6	2	0.5	0	-8	R-	
		# of sites	6	6	6	5	2	6	5	2				

Table 12. Preliminary quality analyses of selected HW wheat lines in 2004.

ENT RY	NAME	PEDIGREE	gpro	Seds	FN	FY	ash	Fpro	L	a	b
1	AC Barrie		0.0	0.0	0	0.0	0.00	0.0	-2.1	-0.27	-1.04
2	Superb		-1.1	-1.0	-172	-1.7	0.06	-0.9	-2.6	-0.03	-1.30
3	AC Elsa		-0.3	-0.5	14	-0.3	0.04	0.0	-2.7	-0.05	-0.96
4	AC Splendor		0.4	8.0	-6	0.1	0.01	0.7	-0.5	-0.14	-0.79
5	Snowbird		-1.1	1.0	2	-1.3	0.03	-0.6	0.0	0.00	0.00
9	HW04003	BW264/ND690	-1.3	-6.0	-35	-1.0	0.00	-1.0	-0.3	-0.16	0.32
10	HW04004	BW264/ND690	-1.4	7.0	-119	-1.6	0.00	-1.2	-0.5	0.02	0.08
15	HW04009	SWP981- 009/SWP981-115	-1.6	-13.5	-89	-0.9	-0.01	-1.5	-0.1	0.15	0.81
16	HW04010	SWP981- 009/SWP981-115	-2.0	-8.0	-73	-1.8	0.01	-1.9	-0.6	0.15	0.49
25	HW04019	BW264*2/SWP1	-0.7	0.0	22	-0.2	0.00	-0.2	-0.3	-0.08	0.45
26	HW04020	BW264*2/SWP1	-1.2	-6.0	-11	-1.5	0.01	-1.1	-0.2	-0.02	0.62
34	HW04028	ND690/X98.29	-1.4	-1.5	5	-3.1	0.01	-1.5	-1.3	0.15	0.32
44	HW04038	ND690/X98.31	-2.4	2.0	-119	-0.5	0.01	-2.4	0.1	0.27	0.92
			6	C	C	C	C	C	2	2	2

Table 13. Pigmentation of early generation populations grown in 1999.

Population	Number of lines	Hunter-Lab values (Whole grain)		
		L ($\pm$ SD)	a ($\pm$ SD)	b ($\pm$ SD)
AC Barrie	Check	43.3 (0.4)	7.2 (0.1)	14.0 (0.1)
AC Elsa	Check	41.7 (0.5)	7.0 (0.1)	14.2 (0.2)
Argent	10	42.6 (0.4)	7.2 (0.1)	15.1 (0.2)
Norquay	2	43.9 (0.3)	6.9 (0.1)	15.2 (0.5)
Cunningham	2	44.3 (0.5)	7.2 (0.1)	16.1 (0.3)
Janz	3	45.0 (0.3)	6.8 (0.3)	16.0 (0.2)
SX96.104	3	46.7 (0.9)	6.9 (0.1)	16.0 (0.2)
SX96.118	1	46.4 (0.1)	7.0 (0.1)	16.0 (0.1)
SX96.107	10	45.7 (0.8)	6.7 (0.2)	15.8 (0.4)
SX96.123	2	45.7 (0.8)	7.2 (0.1)	15.8 (0.3)
SX96.115	1	45.4 (0.2)	6.7 (0.03)	15.1 (0.01)
981-009	1	45.3 (0.1)	7.6 (0)	16.2 (0.1)
SX96.102	2	45.3 (0.6)	7.0 (0.2)	16.0 (0.6)
SX96.113	6	45.2 (0.7)	7.0 (0.3)	15.8 (0.3)
981-129	1	45.1 (0.03)	6.9 (0.01)	15.6 (0.1)
981-136	2	45.0 (0.4)	6.8 (0.1)	15.4 (0.2)
SX96.114	2	44.8 (0.1)	6.9 (0.1)	15.4 (0.1)
SX96.108	7	44.7 (1.5)	6.9 (0.3)	15.6 (0.4)
SX96.105	1	44.4 (0.2)	7.1 (0.1)	15.7 (0.03)

SX96.111	9	43.9 (0.8)	7.0 (0.1)	15.4 (0.3)
981-066	3	43.8 (0.3)	7.0 (0.1)	14.7 (0.2)
981-086	2	43.4 (0.3)	6.9 (0.1)	15.1 (0.1)
SX96.120	2	43.3 (0.2)	7.0 (0.1)	15.3 (0.10)
SX96.122	54	40.7 (0.4)	7.0 (0.2)	14.0 (0.20)

Hunterlab color values: 'L' = 0 (black) to 100 (white); 'a' = +a (red) or -a (green); 'b' = +b (yellow) or -b (blue).

Standard deviations (SD) are given in parentheses.

Table 14. Hard White wheat populations screened for sprouting resistance in 1999.

Population	Number of lines		Sprouting resistant lines (%)
	Retained	Screened	
X98.115 (F3)	84	130	65
X98.31 (F3)	96	215	45
X98.89 (F2)	147	342	43
X98.104 (F2)	124	465	27
X98.108 (F2)	46	191	24
X98.116 (F3)	42	212	20
X98.29 (F3)	106	677	16
X98.30 (F3)	35	251	14
X98.107 (F2)	25	218	11
Total	705	2701	26

Table 15. Percentage germination and sprouting of W98616 and check cultivars grown at Saskatoon, SK 1999-2000

Genotype	Kernel Color _z	12°C		20°C (0 weeks) ^y		20°C (3 weeks) ^y		20°C (6 weeks) ^y		20°C (9 weeks) ^y		Sprouting _x 1999
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	
		----- % -----										

Roblin	R	100	100	99	75	100	100	100	100	100	100	24
Katepwa	R	99	99	97	42	100	100	100	100	100	100	19
Columbus	R	86	88	21	19	30	61	98	93	98	97	2
AC Domain	R	92	70	65	16	86	48	97	93	96	92	7
RL4137	R	65	58	12	4	34	40	98	81	95	88	2
AC Vista	W	98	99	85	68	95	94	100	99	100	99	34
BW264 ^w	W	-	100	-	75	-	98	-	100	-	100	-
W98616	W	50	85	5	12	12	60	83	87	88	91	1
LSD (0.05)		14	6	6	14	16	12	8	6	8	2	5

R = red and W = white, based on 1.25-M NaOH test (Lamkin and Miller 1980).

^y Seed samples were removed from storage at -20°C and stored at 24°C for zero, three, six, or nine weeks. Following storage, seeds were imbibed with water and incubated for one week at 12 or 20°C. First and final germination counts were taken after one week.

^x Spikes were tested for sprouting in a controlled temperature and humidity chamber (Hucl 1994). After seven days of treatment, 10 spikes per plot were rated on a scale of 0 to 5, where 0 = no visible sprouts and 5 = 100% of the primary and secondary floret grains sprouted, respectively. Sprouting (%) = $(\sum I_i / 50) * 100$, where I_i is the score of the i^{th} spike and $I = 1 \dots 10$.

^w Not included in the 1999 test.

Table 16. Comparison of agronomic and quality traits of W98616 and seven check cultivars tested at Saskatoon, SK 1999-2000

Grain yield (kg ha ⁻¹)	Test weight (kg hL ⁻¹)	Kernel weight (mg)	DSE ^z (days)	DPM ^y (days)	Plant height (cm)	Grain protein (%)	Particle size index (%)
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Genotype	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	2000	2000	2000
Roblin	3418	3368	76.5	74.7	34.7	33.5	51.0	56.4	90.3	93.3	90.1	17.1	48
Katepwa	4031	3547	78.5	76.9	33.0	32.6	51.5	58.3	90.3	93.6	95.4	16.5	48
Columbus	3767	2914	79.1	78.0	34.7	34.9	56.0	61.3	93.5	97.8	102.6	17.4	45
AC	3949	3480	78.9	77.9	33.1	34.1	51.0	57.4	90.8	94.3	90.0	18.2	45
Domain	3762	2868	79.1	78.6	32.5	32.9	54.5	60.5	92.0	96.1	98.4	17.5	46
RL4137													
AC Vista	5062	4327	77.1	75.3	40.0	39.1	53.0	58.1	92.5	97.8	83.5	14.9	50
BW264 ^x	-	3521	-	78.1	-	33.7	-	58.4	-	95.5	95.2	16.5	48
W98616	2797	2570	78.5	77.7	31.4	34.2	58.8	60.0	96.3	95.9	96.8	16.3	52
LSD													
(0.05)	462	254	0.4	1.2	1.6	1.5	1	0.6	1.4	1.2	3.0	0.7	4

^z DSE = days to 50% spike emergence.

^y DPM = days to physiological maturity.

^x Not included in the 1999 test.

Table 17. Percentage germination of eight experimental lines and six check cultivars grown at Saskatoon, 2000-2001.

Genotype	Temperature 12°C	Temperature 20°C	Whole grain (NaOH treated) ^z			
			L ^y	a ^y	b ^y	ΔE ^y
Katepwa	100	95	24.0	6.7	9.4	7.1
Columbus	78	18	21.9	6.1	8.3	9.5
AC	99	88	29.8	7.3	13.4	0.0
Snowbird						
AC Vista	100	75	31.5	7.6	14.3	1.9
AUS 1293	88	59	33.9	7.0	15.7	4.7
W98616	69	11	31.4	7.8	14.5	2.0
99 AUS 7	19	1	26.7	7.7	11.6	3.6
99 AUS 8	19	2	26.3	7.6	11.4	4.0
99 AUS 9	48	5	25.0	7.1	10.7	5.5
99 AUS 11	31	3	26.2	7.8	11.4	4.1
99 AUS 22	27	9	25.1	7.0	10.3	5.6
99 AUS 23	33	4	25.5	6.4	10.3	5.4
99 AUS 27	29	3	24.1	6.6	9.9	6.7
99 AUS 34	22	3	24.8	7.4	10.3	5.9
LSD _(0.05)	29.2	8.5	0.8	1.0	0.1	0.8

^z Hunterlab color values: L = 100 (white) to zero (black); a = + (red); b = + (yellow); ΔE=total color difference

^y Based on data collected from only the 2001 test.

Table 18. Hunterlab values for whole grain (NaOH treated), percentage germination, and percentage sprouting for six experimental lines and 10 check cultivars grown in Saskatoon, SK at two locations in 2002

Entry	Kern el color _z	Whole grain ^x (with NaOH ^z)				% Germination		% Sprouting ^w
		L	a	b	ΔE	12°C	20°C	
Katepwa	R	21.7	8.0	8.2	9.4	98	81	23
Columbus	R	20.4	8.0	7.3	11.0	52	17	1
Line 211	R	22.4	8.6	8.9	8.5	28	3	1
CDC-EMDR-4	R	24.7	8.5	10.5	5.8	49	9	6
CDC-EMDR-9	R	22.9	8.0	9.2	7.9	33	3	1
CDC-EMDR-14	R	21.6	7.9	8.1	9.5	47	13	1
AC Snowbird	W	29.4	7.0	12.8	0.5	98	76	13

AC Vista	W	29.8	6.9	12.9	0.5	98	64	31
AUS 1293	W	30.3	7.2	13.7	0.9	90	36	13
W98616	W	29.7	7.3	13.1	0.0	71	13	2
99 AUS-7	R	23.0	8.3	9.2	7.8	36	2	0
99 AUS-8	R	23.1	8.6	9.4	7.7	38	3	1
99 AUS-9	R	22.0	8.3	8.6	9.0	62	6	2
99 AUS-11	R	23.0	8.9	9.4	7.8	58	4	1
99 AUS-23	R	22.3	8.0	8.6	8.7	68	14	2
99 AUS-34	R	22.6	8.8	9.0	8.3	25	3	0
LSD _{0.05}		0.8	0.5	0.5	ND	18	11	8

^z R = red and W = white, based on 1.25-M NaOH test (Lamkin and Miller 1980).

^y Seed samples were imbibed with water and incubated at 12 or 20°C in darkness for one week.

Table 19. Correlation coefficients among Hunterlab values for whole grain (NaOH treated), percentage germination, and percentage sprouting for six AUS lines and 10 checks.

		Whole grain (NaOH treated)				12°C	20°C
		L	a	b	ΔE		
Grai	a	-0.77**					
n	b	1.00**	-0.71**				
	ΔE	-1.00**	0.76**	-0.99**			
12°C		0.62**	-0.76**	0.57*	-0.60*		
20°C		0.46	-0.68**	0.41	-0.45	0.87**	
% sprouting		0.52*	-0.63**	0.48	-0.50*	0.81**	0.88**

*, ** Significant at P=0.05 and P=0.01, respectively.

Table 20. Hunterlab color values for grain treated with NaOH and percentage germination of 30 lines derived from cross#X99.65 and check lines grown at Saskatoon, SK in 2002

ENTRY	Whole grain ^z (NaOH treated ^y)				20°C ^x		12°C ^x	
	L	a	b	ΔE	2 wks	3 wks	2 wks	3 wks
Line 211	23.0	9.2	9.4	8.7	15	28	74	ND ^w
W98616	30.5	7.4	13.4	0.0	20	30	91	ND
Katepwa	21.3	8.6	8.4	10.5	71	81	100	ND
X99.65-11	28.2	8.3	12.4	2.7	5	14	85	ND
X99.65-15	28.1	8.7	12.6	2.8	17	24	75	ND
X99.65-5	27.6	7.5	12	3.2	14	29	83	ND
X99.65-1	26.4	8.8	11.7	4.7	5	9	73	ND
X99.65-6	25.5	9.3	11.1	5.8	7	12	68	ND

X99.65-3	25.4	8.1	10.7	5.8	6	18	79	ND
X99.65-2	24.6	8.9	10.7	6.7	7	15	69	ND
X99.65-7	24.5	8.3	10.2	6.9	5	13	65	ND
X99.65-25	24.2	8.7	10.1	7.2	12	24	72	ND
X99.65-28	24.2	9.2	10.4	7.2	8	15	54	ND
X99.65-26	24.1	9.3	10.4	7.3	3	7	65	ND
X99.65-18	23.8	9.1	9.9	7.7	9	19	71	ND
X99.65-19	23.7	9.1	9.9	7.8	28	36	93	ND
X99.65-30	23.6	8.9	9.8	7.9	6	16	68	ND
X99.65-29	23.5	8.4	9.7	8	13	23	88	ND
X99.65-4	23.4	9.3	9.8	8.2	10	22	81	ND
X99.65-10	23.2	8.6	9.6	8.3	10	20	74	ND
X99.65-12	23.2	8.3	9.3	8.4	6	11	72	ND
X99.65-23	23.2	8.7	9.7	8.3	7	13	69	ND
X99.65-14	23.1	6.3	9.5	8.4	4	4	65	ND
X99.65-17	23.1	8.9	9.3	8.6	4	8	62	ND
X99.65-20	23	8.5	9.3	8.6	9	20	76	ND
X99.65-9	22.9	8.4	9	8.8	9	18	67	ND
X99.65-16	22.7	8.9	9.4	8.9	4	6	58	ND
X99.65-27	22.6	8.3	9	9.1	12	21	79	ND
X99.65-8	22.5	8.5	9.2	9.1	3	5	63	ND
X99.65-21	22.5	8.6	8.9	9.3	8	12	74	ND
X99.65-22	22.5	9.2	9.3	9.2	7	10	70	ND
X99.65-24	22.4	8.3	8.9	9.3	7	10	64	ND
X99.65-13	22.3	8.6	8.8	9.5	4	17	65	ND
LSD _{0.05}	1.5	1.3	1.0	ND	15	20	9	ND
Statistics								
No. of lines	30	30	30		30	30	30	30
Mean	24.0	8.6	10.0	7.5	8.3	15.7	71.4	ND
SD	1.7	0.6	1.0	1.9	5.1	7.4	8.8	ND
Minimum	22.3	6.3	8.8	2.7	3.0	4.0	54.0	ND
Maximum	28.2	9.3	12.6	9.5	28.0	36.0	92.5	ND

^z L = 100 (white) to zero (black); a = + (red); b = + (yellow); ΔE = total color difference.

^y R = red and W = white, based on 1.25-M NaOH test.

^x Seed samples were removed from storage at -20°C, imbibed with water, and incubated at 12 or 20°C in darkness. Germination counts taken at 14-d and 21-d.

^w ND=Not determined to date.

Table 21. Correlation coefficients among Hunterlab values for whole grain (NaOH treated) and percentage germination for 33 entry test evaluating cross#X99.65 in 2002.

	Whole grain (NaOH treated)				20°C 2 wks
	L	a	b	ΔE	
Grain					
a	-0.27				
b	0.99**	-0.19			
ΔE	-1.00**	0.28	-0.99**		
20°C 2 wks	-0.08	0.00	-0.09	0.07	
12°C 2 wks	0.29	-0.18	0.25	-0.29	0.70**

*, ** Significant at P=0.05 and P=0.01, respectively.

Table 22. Hunterlab color values for grain treated with NaOH and percentage germination of nine lines derived from cross#X99.65 and check lines grown at Saskatoon, SK in 2003

Entry ^a	Color ^w	Whole grain ^z (NaOH treated)			12 C ^y			20 C ^y		
		L	a	b	1 wk	2 wk	3 wk	1 wk	2 wk	3 wk
Katepwa	Red	21.8	6.6	7.5	100	100	100	88	99	100
Line 211	Red	23.8	7.6	8.9	42	72	76	3	15	36
W98616	White	30.8	7.5	13.5	84	98	99	6	16	34
X99.65-1	White	33.6	6.7	14.7	88	97	99	20	37	50
X99.65-2	White	31.1	7.4	13.7	93	99	99	28	72	89
X99.65-3	White	30.8	7.0	13.4	91	99	99	11	45	68
X99.65-5	White	31.4	7.4	14.0	81	96	99	16	42	72
X99.65-6	Red	24.4	7.8	10.0	66	91	94	4	13	33
X99.65-7	White	30.0	7.1	13.0	88	98	98	13	25	42
X99.65-11	White	31.8	7.0	13.7	90	97	98	33	50	67
X99.65-15	White	33.7	6.8	14.8	87	97	98	12	18	30
X99.65-28	White	32.3	7.4	14.5	89	98	99	17	61	87
LSD _{0.05}		1.0	0.3	0.6	8	4	4	12	18	22

^z L = 100 (white) to zero (black); a = + (red); b = + (yellow); ΔE = total color difference.

^y Seed samples were removed from storage at -20°C, imbibed with water, and incubated at 12 or 20°C in darkness. Germination counts taken at 14-d and 21-d.

^a Katepwa=poor sprouting resistance; Line 211 and W98616=good sprouting resistance.

^w R = red and W = white, based on 1.25-M NaOH test.

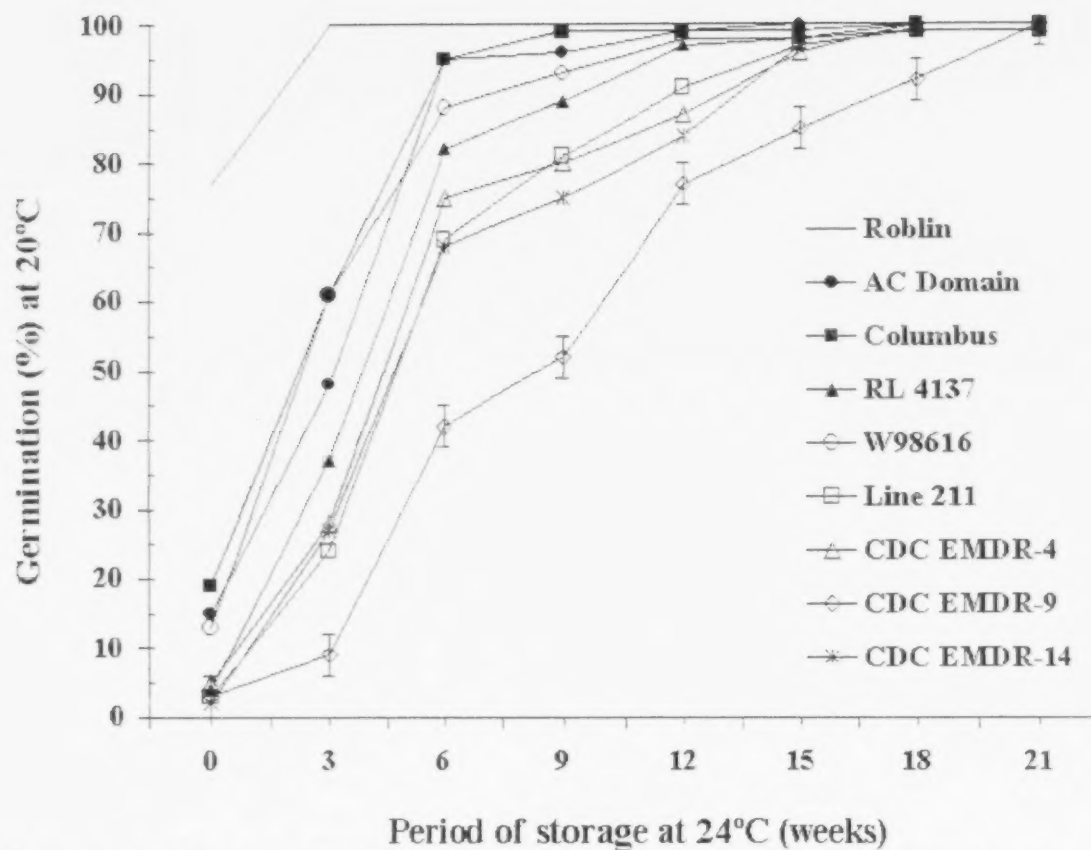


Fig. 1. Effect of storage at 24°C for zero to 21 weeks, prior to germination at 20°C for one week, on germination (%) for non-dormant Roblin and eight highly dormant wheat genotypes. Standard errors, represented by vertical bars, within each sampling day are similar for all genotypes.

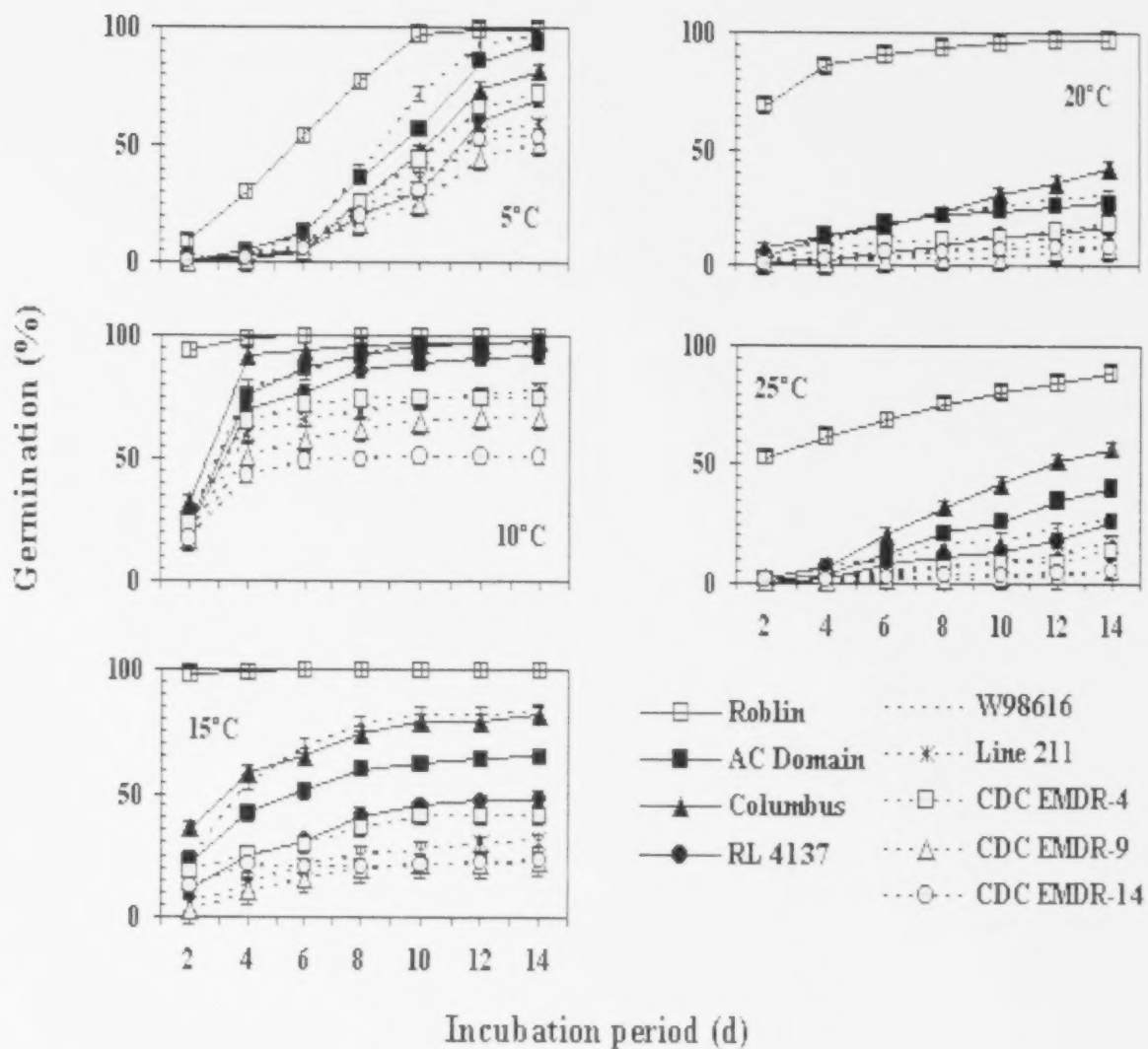


Fig. 2. Germination at 5, 10, 15, 20, and 25°C (in darkness) in non-dormant Roblin and eight highly dormant wheat genotypes. Vertical bars represent standard errors.

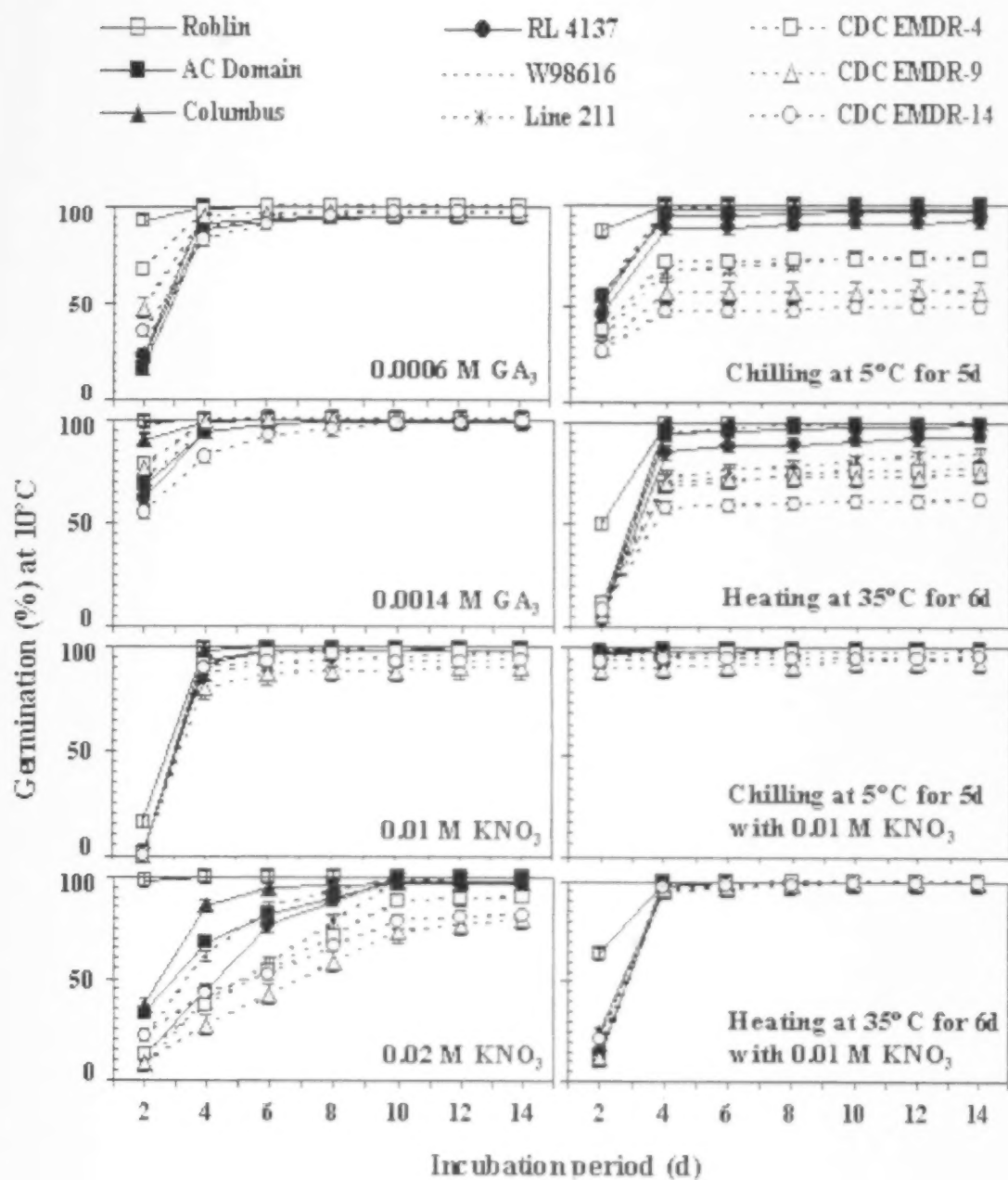


Fig. 3. Germination at 10°C in darkness for 14d for non-dormant Roblin and eight highly dormant wheat genotypes using eight pre-treatments. Vertical bars represent standard errors.

Table 23. Effect of five pre-treatments on seedling length, internode length, and biomass yield in Roblin, Columbus, and CDC-EMDR-9

Pre-treatment	Seedling length (cm)	First internode length (cm)	Biomass yield (g)
<u>Roblin</u>			
Water	46.0	5.8	1.0
0.0006 M GA ₃	52.9	10.2	1.2
0.0014 M GA ₃	56.4	12.2	1.2
Chill and 0.01 M KNO ₃	46.1	5.8	1.1
Heat and 0.01 M KNO ₃	47.3	6.6	1.1
LSD (0.05)	2.7	0.8	NS
<u>Columbus</u>			
Water	44.1	7.3	1.2
0.0006 M GA ₃	47.0	9.7	1.1
0.0014 M GA ₃	49.6	11.3	1.1
Chill and 0.01 M KNO ₃	44.1	7.5	1.2
Heat and 0.01 M KNO ₃	43.9	7.1	1.1
LSD (0.05)	2.3	0.9	NS
<u>CDC EMDR-9</u>			
Water	46.3	7.6	1.2
0.0006 M GA ₃	49.1	10.0	1.0
0.0014 M GA ₃	52.3	11.4	1.2
Chill and 0.01 M KNO ₃	45.0	6.6	1.1
Heat and 0.01 M KNO ₃	44.8	6.6	1.1
LSD (0.05)	2.5	1.1	NS

Table 24. Means for six agronomic and two quality traits for 79 wheat genotypes grown in Saskatchewan at two locations in 2000 and 2001.

Genotype	Accession number	Grain yield ('00 kg ha ⁻¹)	Heading (d)	Maturity (d)	Plant height (cm)	Test weight (kg hL ⁻¹)	1000-Kernel weight (g)	Grain protein † (%)	Kernel grinding time ‡ (s)
<u>Hard red (n=7)</u>									
Roblin		34.8	55.4	87.8	90.9	75.4	31.3	15.0	19.0
AC Elsa		35.2	57.9	87.5	86.5	78.4	31.3	14.8	16.8
AC Barrie		37.9	58.0	90.5	90.1	80.2	33.1	13.9	17.6
CDC Teal		32.2	57.8	88.3	88.3	77.1	30.7	14.3	18.4
Laura		40.2	59.0	92.0	92.5	79.9	32.8	14.1	18.0
AC Domain		33.0	56.6	86.9	85.8	79.3	32.2	14.7	17.5
Columbus		30.8	60.5	91.0	102.8	80.2	33.8	13.7	17.9
<u>Hard white (n=64)</u>									
AC Karma		40.0	58.8	94.4	79.6	79.8	36.3	12.3	16.9
AC Vista		37.5	58.4	90.8	84.6	77.3	37.8	12.9	16.1
Snowbird		36.1	57.6	89.4	89.1	79.7	32.8	13.7	19.0
Argent		41.0	57.8	92.8	85.9	79.9	38.1	13.2	16.1
Kiata	AUS 24259	33.1	58.4	93.8	66.9	78.8	31.1	12.4	17.4
Suneca	AUS 21820	29.1	59.9	95.0	79.5	82.1	37.4	13.8	18.4
Gatcher	AUS 98008	34.3	56.8	90.5	84.6	76.9	35.8	11.8	16.4
Kelalac	AUS 24507	35.2	55.5	94.3	64.3	78.1	30.4	12.4	18.5
Tailorbird	AUS 27190	26.6	58.6	90.5	76.6	78.0	31.5	13.3	15.3
Banks	AUS 20599	33.1	58.5	94.8	71.0	78.1	31.3	12.4	15.8
Moray	AUS 24270	33.2	59.6	97.3	64.0	79.4	33.2	11.8	17.4
Dollarbird	AUS 23824	32.2	57.9	91.8	76.4	79.1	32.7	12.1	15.6
Goldmark	AUS 27660	32.4	61.6	96.0	70.3	79.1	33.0	12.0	15.9
Sunbird	AUS 23456	33.9	58.9	95.8	66.0	79.5	32.1	11.7	17.4
Angas	AUS 25418	32.5	56.1	93.5	66.5	78.5	36.7	11.9	16.5
Hartog	AUS 21533	34.8	58.4	92.5	79.1	79.3	32.7	12.3	15.4
Condor	AUS 16036	34.6	58.4	95.0	73.8	81.0	33.6	11.4	16.0
Lark	AUS	34.4	59.3	94.5	68.9	78.5	31.9	13.2	16.6

	24849								
Schomburgk	AUS 23325	34.5	56.8	93.0	66.1	77.6	33.7	12.9	16.6
Houtman	AUS 25868	32.3	60.0	93.3	73.5	76.5	32.3	11.6	15.4
Cascades	AUS 25575	37.3	57.8	96.5	70.4	78.9	38.7	11.5	17.1
Halberd	AUS 11612	34.2	58.9	93.8	78.9	79.1	33.1	12.1	18.6
Silverstar	AUS 27661	36.2	56.5	94.5	69.3	78.8	30.5	12.0	16.9
Kalannie	AUS 27189	36.3	56.0	92.0	76.3	78.8	36.4	11.9	18.3
Krichauff	AUS 27203	39.4	59.0	96.0	71.4	79.2	31.3	12.6	17.4
Sunmist	AUS 25869	38.1	59.0	94.3	71.1	78.5	30.2	13.7	16.6
Barunga	AUS 25602	29.8	59.5	96.0	71.3	79.2	31.8	12.5	15.8
Baxter	AUS 27694	32.4	58.6	93.3	77.8	78.8	33.9	13.2	17.3
Leichhardt	AUS 26192	30.9	58.6	93.8	80.4	80.5	35.3	11.9	15.4
Rowan	AUS 25927	37.3	59.5	93.8	82.5	79.3	31.9	11.5	15.8
Tasman	AUS 25557	33.4	60.5	95.0	65.9	78.4	32.7	12.2	19.1
Sunfield	AUS 24335	35.7	55.9	93.0	71.9	80.4	32.9	12.0	18.3
Sunland	AUS 25931	36.9	59.5	96.3	73.4	80.8	33.4	11.4	16.5
Beulah	AUS 25567	36.2	61.1	97.5	69.1	79.8	33.0	12.4	17.1
Sunbrook	AUS 27195	37.2	62.4	96.5	77.3	81.9	34.5	12.3	15.6
BT- Schomburgk	AUS 25600	31.8	56.3	93.8	71.8	78.7	31.7	12.3	16.3
Molineux	AUS 24457	33.8	60.9	94.8	73.4	78.7	30.2	12.7	17.1
Pelsart	AUS 25558	33.3	58.0	92.8	73.1	79.7	28.6	12.6	16.5
Miskle	AUS 24458	35.5	59.3	95.3	70.8	78.7	32.2	12.6	17.0
Wilgoyne	AUS 24456	32.1	56.4	93.6	76.1	79.0	41.2	13.3	17.1
Cook	AUS 20275	36.3	59.3	95.5	70.9	81.4	32.2	12.1	16.3
Minto	AUS 24260	33.2	59.8	96.5	64.3	79.8	30.7	12.3	18.3

Perouse	AUS 24793	35.7	60.8	97.0	76.1	80.3	32.9	12.6	17.5
Janz	AUS 24794	36.5	59.5	96.5	67.8	79.7	31.8	12.7	17.6
Tern	AUS 26169	23.6	63.3	97.0	101.1	80.2	44.7	15.7	17.8
Carnamah	AUS 27194	35.1	60.6	95.3	68.4	79.3	35.8	13.0	16.8
Ouyen	AUS 25571	25.9	59.4	96.0	64.0	79.5	32.1	11.5	15.3
Goroke	AUS 25568	34.2	62.1	97.5	65.8	78.3	29.9	12.6	18.4
Stiletto	AUS 25923	37.8	59.1	97.3	73.8	80.2	38.6	12.2	15.9
Stretton	AUS 25597	30.3	59.3	95.0	67.3	75.6	33.1	12.9	15.5
Sunvale	AUS 25930	34.1	61.0	97.3	66.9	81.1	33.0	12.8	16.6
Cunningham	AUS 25046	38.5	60.4	96.3	70.4	81.1	34.1	12.2	18.3
Sunbri	AUS 25112	32.7	60.0	96.3	70.4	82.4	31.7	12.4	15.9
Warimba	AUS 98012	31.4	57.9	95.0	66.9	76.2	35.0	11.9	15.9
Petrel	AUS 27191	28.0	60.1	94.5	98.9	81.6	40.6	14.7	20.4
Torres	AUS 21962	30.6	60.6	96.5	62.1	78.5	31.2	12.8	18.4
Excalibur	AUS 25292	30.9	61.1	95.9	66.6	74.7	33.6	12.8	15.0
Amery	AUS 25598	34.5	59.9	96.0	70.3	76.4	34.5	11.3	17.0
Trident	AUS 25924	37.3	57.9	97.3	69.1	80.2	37.6	13.0	15.5
Gutha	AUS 21823	35.0	57.9	91.8	79.9	75.7	35.3	11.7	16.4
Yarralinka	AUS 24350	37.4	61.8	96.5	72.0	77.4	32.5	12.5	19.3
Eagle	AUS 95270	32.6	56.6	91.3	82.9	77.5	34.9	12.4	15.9
Kite	AUS 11849	33.2	59.0	95.0	75.0	77.7	36.0	12.5	16.6
Sunelg	AUS 22657	28.0	58.5	93.8	66.9	78.5	33.7	12.9	15.9
<u>Soft white (n=8)</u>									
AC Reed		39.3	58.5	94.0	76.6	77.5	33.2	11.6	31.5
Vectis	AUS 25925	35.6	57.9	92.5	74.0	73.6	36.4	11.9	38.5
Tatiara	AUS	37.3	59.3	94.8	74.6	75.4	33.7	11.1	31.0

	24137								
Sunset	AUS 1335	28.1	53.9	86.3	85.5	78.5	35.2	13.9	35.1
Katunga	AUS 25468	35.2	62.4	96.8	70.3	77.8	31.9	12.0	38.6
Eradu	AUS 21110	35.5	60.4	95.0	76.4	79.8	36.4	12.9	33.9
Reeves	AUS 24851	36.5	59.9	95.0	80.5	79.8	37.8	12.0	31.1
Chile Late	AUS 108	31.1	55.3	89.3	90.0	79.6	36.0	14.3	32.3
LSD (0.05)		8.8	1.4	2.6	7.6	2.2	3.4	1.2	2.2
Statistics									
Grand mean §									
Hard red		34.9 a	57.9 a	89.1 b	91.0 a	78.6 a	32.2 b	14.4 a	17.9 b
Hard white		33.9 a	59.0 a	94.7 a	73.4 b	79.0 a	33.8 a	12.5 b	16.9 c
Soft white		34.8 a	58.5 a	93.0 a	78.5 b	77.8 a	35.1 a	12.5 b	34.0 a
Range									
Hard red		30.8- 40.2	55.4-60.5	86.9-92.0	85.8- 102.8	75.4- 80.2	30.7- 33.8	13.7- 15.0	16.8-19.0
Hard white		23.6- 41.0	55.5-63.3	89.4-97.5	62.1- 101.1	74.7- 82.4	28.6- 44.7	11.3- 15.7	15.0-20.4
Soft white		28.1- 39.3	53.9-62.4	86.3-96.8	70.3- 90.0	73.6- 79.8	31.9- 37.8	11.1- 14.3	31.0- 38.60

† 14 % moisture basis.

‡ A lower value is indicative of a harder kernel texture.

§ Within a column, grand means followed by the same letter are not significantly different at $P=0.05$.

Table 25. Means for grain (without/with NaOH) and meal color values, yellow pigment (YP), and lutein for 79 wheat genotypes.

Genotype	Grain †				Grain (NaOH treated)				Meal				YP	Lutein
	L	a	b	ΔE	L	a	b	ΔE	L	a	b	ΔE	($\mu\text{g g}^{-1}$)	($\mu\text{g g}^{-1}$)
<u>Hard red (n=7)</u>														
Roblin	43.4	7.1	14.1	2.6	24.1	9.3	10.3	10.6	81.1	2.5	10.1	1.7	3.0	2.2
AC Elsa	42.4	7.6	14.5	3.0	25.8	9.3	11.3	8.7	81.3	2.5	10.2	1.4	3.1	2.3
AC Barrie	42.3	7.9	14.1	3.3	23.7	9.7	10.1	11.1	82.5	2.3	10.3	0.3	3.1	2.4
CDC Teal	41.8	7.3	13.8	3.9	23.0	8.9	9.4	12.0	80.2	2.6	10.6	2.5	3.4	2.5
Laura	41.3	7.6	14.3	4.0	25.5	9.5	11.5	8.8	80.1	2.5	10.1	2.6	3.1	2.3
AC Domain	41.2	7.3	13.7	4.4	23.7	9.1	10.0	11.1	81.2	2.4	9.8	1.7	2.8	2.0
Columbus	40.9	7.4	13.6	4.7	22.7	9.2	9.2	12.4	81.4	2.4	9.9	1.4	2.8	2.1
<u>Hard white (n=64)</u>														
AC Karma	48.5	7.5	17.4	3.8	36.7	7.9	16.7	3.6	83.7	2.0	10.1	1.1	3.1	2.3
AC Vista	46.8	7.6	16.5	2.0	34.8	8.5	16.3	1.7	83.3	2.0	10.5	0.7	2.9	2.2
Snowbird	44.9	7.8	16.1	0.0	33.3	8.3	15.5	0.0	82.7	2.3	10.5	0.0	2.6	1.9
Argent	43.5	7.9	15.7	1.5	32.5	8.8	15.2	1.0	81.3	2.3	10.8	1.4	3.2	2.3
Kiata	49.0	7.8	17.5	4.3	37.4	8.4	17.2	4.4	83.3	2.1	10.1	0.7	3.3	2.4
Suneca	48.4	7.4	17.1	3.7	35.6	8.1	16.6	2.6	83.3	2.0	10.2	0.7	2.9	2.1
Gatcher	48.1	7.3	16.6	3.3	34.6	8.6	15.9	1.4	83.0	2.2	10.4	0.3	3.0	2.2
Kelalac	47.9	7.5	17.1	3.2	36.1	8.0	16.5	3.0	82.8	2.2	9.8	0.7	3.4	2.5
Tailorbird	47.9	7.3	16.8	3.1	34.0	8.2	15.9	0.8	82.1	2.1	10.4	0.6	3.0	2.2
Banks	47.8	7.9	17.3	3.1	35.7	8.2	16.4	2.6	82.2	2.2	10.7	0.5	3.2	2.3
Moray	47.8	7.7	17.1	3.1	36.2	8.4	16.8	3.2	82.6	2.2	10.7	0.2	3.2	2.3
Dollarbird	47.7	7.3	16.8	2.9	34.7	8.3	16.2	1.6	82.5	2.2	10.6	0.2	3.1	2.2
Goldmark	47.7	7.5	17.2	3.0	35.4	8.5	16.6	2.4	83.3	2.0	10.7	0.7	3.6	2.8
Sunbird	47.6	7.8	17.3	3.0	36.5	8.2	16.9	3.5	82.4	2.1	10.4	0.4	3.0	2.2
Angas	47.3	8.1	17.6	2.8	35.9	8.6	17.3	3.2	82.6	2.1	11.3	0.8	4.6	3.5
Hartog	47.3	7.4	16.6	2.5	34.8	8.1	16.1	1.6	82.4	2.1	10.6	0.4	3.2	2.3
Condor	47.2	7.7	17.1	2.5	36.3	8.1	16.5	3.2	82.3	2.1	10.7	0.5	3.0	2.2
Lark	47.1	7.9	17.1	2.4	35.3	8.3	16.3	2.2	83.3	2.0	9.6	1.1	3.1	2.3
Schomburgk	47.1	7.8	17.4	2.6	35.5	8.4	16.8	2.6	83.0	2.2	11.3	0.9	4.6	3.5
Houtman	46.9	7.2	16.6	2.1	34.4	8.2	16.2	1.3	81.8	2.2	11.0	1.0	3.4	2.5
Cascades	46.7	7.9	17.1	2.1	35.3	8.8	16.9	2.5	83.4	2.0	10.3	0.8	4.3	3.2
Halberd	46.7	7.8	17.2	2.1	34.8	8.3	15.9	1.6	83.1	2.1	10.6	0.5	3.1	2.3
Silverstar	46.7	7.7	16.6	1.9	34.2	8.5	15.9	1.0	81.2	2.5	10.5	1.5	3.1	2.2
Kalannie	46.6	7.5	16.5	1.8	35.0	8.2	16.1	1.8	83.8	2.0	9.7	1.4	2.6	1.9
Krichauff	46.6	8.2	17.4	2.2	35.5	8.8	16.9	2.7	82.6	2.2	11.1	0.6	4.7	3.6
Sunmist	46.6	7.3	16.7	1.9	34.8	8.2	15.9	1.6	82.5	2.0	10.7	0.4	2.8	2.0
Barunga	46.5	7.5	16.8	1.8	36.0	8.1	16.5	2.9	82.7	2.0	10.2	0.4	2.9	2.2
Baxter	46.4	7.0	16.1	1.7	34.6	8.1	15.7	1.3	82.1	2.2	10.2	0.7	2.5	1.8
Leichhardt	46.4	7.3	16.4	1.6	34.7	8.1	16.2	1.6	82.4	2.0	10.7	0.5	3.3	2.4
Rowan	46.4	7.4	16.6	1.6	34.8	8.3	16.2	1.7	82.0	2.3	11.0	0.9	3.5	2.6
Tasman	46.4	7.7	16.8	1.7	34.8	8.1	16.2	1.7	82.8	2.2	10.0	0.5	3.3	2.4
Sunfield	46.3	7.6	16.7	1.5	35.5	8.3	16.3	2.3	82.2	2.2	10.2	0.6	2.8	2.0

Sunland	46.3	7.5	16.8	1.6	35.5	8.1	16.3	2.3	82.1	2.3	10.3	0.6	2.8	2.0
Beulah	46.2	7.5	17.1	1.7	35.5	8.0	16.7	2.5	81.8	2.1	10.9	1.0	4.2	3.2
Sunbrook	46.2	7.4	16.6	1.4	35.8	7.9	16.4	2.7	82.2	2.2	10.6	0.5	2.9	2.1
BT-Schomburgk	46.1	8.0	17.4	1.8	35.6	8.7	17.0	2.8	81.5	2.4	11.8	1.8	4.8	3.7
Molineux	46.1	7.7	16.6	1.3	35.4	8.0	15.8	2.1	84.1	2.0	10.1	1.5	2.7	2.0
Pelsart	46.1	7.7	16.5	1.3	35.8	7.9	16.5	2.7	82.7	2.2	10.6	0.1	2.9	2.1
Miskle	46.0	7.3	16.4	1.2	34.4	8.2	15.7	1.1	82.2	2.2	10.5	0.5	2.8	2.0
Wilgoyne	45.9	7.2	16.2	1.2	34.6	8.2	16.1	1.4	82.4	2.2	10.5	0.3	2.7	2.0
Cook	45.8	7.7	16.5	1.0	35.6	7.9	16.2	2.4	82.5	2.2	10.3	0.3	2.6	1.9
Minto	45.7	8.0	16.8	1.1	34.8	8.4	16.0	1.6	81.6	2.3	10.5	1.1	3.1	2.2
Perouse	45.6	7.7	16.3	0.7	34.5	8.0	15.7	1.3	81.6	2.1	9.9	1.3	2.6	1.9
Janz	45.5	7.8	16.5	0.7	35.3	8.1	16.1	2.1	83.0	2.2	10.2	0.4	3.0	2.1
Tern	45.4	7.6	16.6	0.7	34.0	8.0	16.3	1.1	83.0	2.0	10.6	0.4	4.5	3.3
Carnamah	45.3	7.5	16.3	0.5	34.7	8.2	16.3	1.6	81.5	2.4	10.7	1.2	3.3	2.4
Ouyen	45.3	7.5	16.3	0.5	35.1	8.1	16.1	1.9	81.2	2.4	10.9	1.6	2.8	2.0
Goroke	45.2	7.7	16.0	0.3	33.7	8.0	15.5	0.5	81.7	2.3	10.7	1.0	3.0	2.1
Stiletto	45.2	8.0	16.7	0.7	35.6	8.2	16.5	2.5	82.2	2.0	10.6	0.6	3.3	2.5
Stretton	45.2	7.3	16.2	0.6	33.5	8.5	15.6	0.3	81.8	2.2	10.8	1.0	3.3	2.4
Sunvale	45.2	7.3	16.0	0.6	35.5	7.7	16.1	2.4	81.3	2.3	10.4	1.4	2.7	2.0
Cunningham	44.8	7.8	16.4	0.3	35.1	8.1	16.1	1.9	81.9	2.3	10.6	0.8	2.7	2.0
Sunbri	44.8	7.4	16.1	0.4	34.7	7.8	15.8	1.5	81.8	2.3	10.5	0.9	2.6	1.9
Warimba	44.8	7.4	16.1	0.4	33.3	8.4	15.6	0.1	82.3	2.1	10.1	0.6	2.7	2.0
Petrel	44.5	7.6	16.4	0.5	33.1	8.4	15.5	0.2	83.4	2.0	10.0	0.9	3.4	2.6
Torres	44.4	8.0	16.4	0.6	34.1	8.4	15.9	0.9	81.9	2.3	10.3	0.8	2.6	1.9
Excalibur	44.3	7.5	16.1	0.7	34.4	8.2	16.1	1.3	81.8	2.1	10.8	1.0	4.0	2.9
Amery	44.2	7.6	16.3	0.8	33.5	8.3	15.5	0.2	82.3	2.3	10.5	0.4	3.3	2.5
Trident	44.2	8.0	16.4	0.8	34.9	8.2	16.3	1.8	82.8	2.2	10.6	0.2	3.5	2.6
Gutha	44.1	7.3	15.7	1.0	33.6	8.5	15.7	0.4	81.6	2.3	10.0	1.2	2.9	2.1
Yarralinka	43.4	7.9	16.1	1.5	33.3	8.6	15.8	0.4	82.7	2.1	9.9	0.6	3.0	2.1
Eagle	43.3	7.3	15.5	1.8	31.7	8.4	14.9	1.7	81.0	2.4	10.5	1.7	2.9	2.1
Kite	43.1	7.5	15.6	1.9	33.8	8.4	15.8	0.6	82.1	2.2	10.3	0.6	3.1	2.3
Sunelg	42.5	7.6	15.6	2.5	33.4	8.2	15.4	0.2	81.9	2.2	10.4	0.8	3.2	2.4
<u>Soft white</u>														
<u>(n=8)</u>														
AC Reed	49.3	7.9	18.4	5.0	36.4	8.2	17.0	3.4	84.6	1.8	9.4	2.3	3.2	2.4
Vectis	50.4	7.8	19.1	6.3	38.1	8.4	17.9	5.4	84.6	1.8	9.9	2.1	4.7	3.6
Tatiara	50.0	7.8	19.1	5.9	37.1	9.1	17.8	4.5	83.5	2.0	10.4	0.9	4.6	3.5
Sunset	49.2	7.5	18.0	4.7	35.5	8.2	16.6	2.5	84.9	1.8	9.4	2.5	3.0	2.3
Katunga	49.0	8.3	18.9	5.0	36.8	8.5	17.4	4.0	83.5	2.0	10.2	0.9	3.5	2.6
Eradu	48.7	7.5	17.9	4.2	36.2	8.3	17.1	3.3	83.8	1.9	9.5	1.5	2.7	2.0
Reeves	48.6	7.8	18.0	4.2	36.7	8.8	17.2	3.8	84.5	1.8	8.9	2.5	2.7	2.0
Chile Late	47.9	8.0	17.5	3.3	34.9	8.4	16.4	1.8	84.2	1.8	9.4	1.9	3.3	2.4
LSD (0.05)	1.0	0.2	0.5	1.1	1.5	0.5	0.8	1.3	2.0	0.4	0.9	1.6	0.4	0.3

Statistics
Grand mean

†															
‡															
Hard red	41.9	7.5	14.0	3.7	24.1	9.3	10.3	10.7	81.1	2.5	10.1	1.7	3.0	2.3	a
	c	b	c	b	c	a	c	a	c	a	b	bd	a		
Hard white	46.0	7.6	16.6	1.7	34.8	8.3	16.2	1.8	82.4	2.2	10.5	0.8	3.2	2.3	a
	b	b	b	c	b	c	b	c	b	b	a	c	a		
Soft white	49.1	7.8	18.4	4.8	36.6	8.5	17.2	3.6	84.2	1.9	9.6	1.8	3.6	2.6	a
	a	a	a	a	a	b	a	b	a	c	c	ad	a		
Range															
Hard red	40.9-	7.1-	13.6-	2.6-	22.7-	8.9-	9.2-	8.7-	80.1-	2.3-	9.8-	0.3-	2.8-	2.0-	
	43.4	7.9	14.5	4.7	25.8	9.7	11.5	12.4	82.5	2.6	10.6	2.6	3.4	2.5	
Hard white	42.5-	7.0-	15.5-	0.0-	31.7-	7.7-	14.9-	0.0-	81.0-	2.0-	9.6-	0.0-	2.5-	1.8-	
	49.0	8.2	17.6	4.3	37.4	8.8	17.3	4.4	84.1	2.5	11.8	1.8	4.8	3.7	
Soft white	47.9-	7.5-	17.5-	3.3-	34.9-	8.2-	16.4-	1.8-	83.5-	1.8-	8.9-	0.9-	2.7-	2.0-	
	50.4	8.3	19.1	6.3	38.1	9.1	17.9	5.4	84.9	2.0	10.4	2.5	4.7	3.6	

† L = 100 (white) to zero (black); a = + (red); b = + (yellow); ΔE = total color difference.

‡ Within a column, grand means followed by the same letter are not significantly different at P=0.05.

Table 26. Analysis of variance for grain (without/with NaOH) and meal color values, yellow pigment, and lutein for 79 wheat genotypes.

Source of variation	DF	Grain			Grain (NaOH treated)			Meal			Yellow	
		L	a	b	L	a	b	L	a	b	pigment	Lutein
		-----Mean squares-----										
Years (Y)	1	1.1	53.7 **	8.2	3.4	116.9	15.9	9.9	0.1	0.003	0.01	3.2 *
Locations (L)	1	307.6	0.1	16.3	33.9	3.2	11.4	3.2	0.0001	0.1	0.1	0.1
Y x L	1	307.6 **	0.1	16.3 **	33.9	3.2	11.4	3.2	0.0001	0.1	0.1	0.1
Replications (YL)	4	2.2 **	0.3 **	0.4 **	6.9 **	0.8 **	3.5 **	3.1	0.4 **	0.9	1.0 **	0.1 **
Genotypes (G)	78	34.2 **	0.6 **	9.3 **	89.0 **	1.2 **	26.6 **	7.5 **	0.2 **	1.7 **	2.5 **	1.6 **
G x L	78	0.6	0.01	0.1	0.6	0.1	0.2	0.2	0.01	0.02	0.02	0.01
G x Y	78	1.0 *	0.1 **	0.2 **	2.2 **	0.2 **	0.6 **	3.9 **	0.1 **	0.8 **	0.2 **	0.1 **
G x L x Y	78	0.6 **	0.01	0.1 **	0.6	0.1	0.2	0.2	0.01	0.02	0.02	0.01
Error	312											

*, ** Significant at P=0.05 and P=0.01, respectively.

Table 27. Means of six agronomic traits, grain protein, kernel grinding time, grain (without/with NaOH) and meal color values, yellow pigment, and lutein for wheat genotypes.

Trait	Hard red (n=7)		Hard white (n=64)		Soft white (n=8)	
	Year 2000	Difference ‡	Year 2000	Difference	Year 2000	Difference
Grain yield ('00 kg ha ⁻¹)	43.1	+15.4 **	42.2	+16.4 **	41.1	+15.4 **
Heading (d)	57.8	-1.1	58.9	-0.1	58.1	-0.7
Maturity (d)	93.1	+3.2 **	98.4	+7.9 **	96.5	+7.4 **
Plant height (cm)	100.7	+28.5 **	79.4	+10.9 **	84.6	+13.4 **
Test weight (kg hL ⁻¹)	78.5	-1.5	78.1	-1.7 **	76.8	-3.0 **
1000-Kernel weight (g)	34.7	+1.6 *	35.7	+4.0 **	36.7	+5.0 **
Grain protein (%)	12.6	-1.7 **	12.3	-0.6 **	12.4	-0.7
Grinding time (s)	20.5	+1.6	17.7	+0.3	35.6	+3.1
Grain †						
L	42.1	+0.3	46.1	+0.1	48.9	-0.4
a	7.3	-0.4 *	7.3	-0.6 **	7.6	-0.4 *

*, ** Significantly different from zero at P=0.05 and P=0.01, respectively.

[illegible]

L	0.14	0.67 **	0.65 **	0.25 *	0.68 **	0.52 **	0.16	0.55 **			
a	-0.19	-0.61 **	- 0.58 **	- 0.14	- 0.60 **	- 0.46 **	- 0.09	- 0.50 **	- 0.85 **		
b	-0.13	-0.58 **	- 0.28 *	- 0.01	- 0.24 *	- 0.17	- 0.04	- 0.09	- 0.62 **	- 0.58 **	
Yellow pigment	-0.03	0.15	0.23 **	0.39 **	0.46 **	0.26 *	0.44 **	0.54 **	0.13	- 0.14	0.43 **
Lutein	-0.03	0.17	0.24 *	0.39 **	0.48 **	0.28 *	0.45 **	0.56 **	0.17	- 0.17	0.99 ** 0.41 **

*, ** Significant at P=0.05 and P=0.01, respectively.

Table 29. Hunterlab values for whole grain (without NaOH treatment) for four checks
Hunterlab for whole grain samples (Untreated)^z

Entry	Name	L			a			b		
		2002	2003	Mean	2002	2003	Mea	2002	2003	Mean
1	ND690	30.3	32.9	31.6	5.0	6.6	5.8	9.4	11.1	10.2
2	W98616	31.1	33.1	32.1	5.7	6.9	6.3	10.4	11.9	11.1
3	AUS140	30.9	34.1	32.5	5.4	6.7	6.1	9.9	11.9	10.9
4	RL4137	28.4	29.8	29.1	5.0	6.2	5.6	8.4	9.2	8.8
LSD		1.4	0.9	0.9	0.5	0.3	0.4	0.6	0.4	0.4
Statistics		151 DH lines (n=151)								
Mean		31.0	33.3	32.1	5.2	6.7	6.0	10.0	11.5	10.7
SD		0.7	0.7	0.6	0.3	0.2	0.2	0.3	0.3	0.2
SE		0.1	0.1	0.1	0.02	0.02	0.02	0.03	0.02	0.02
Min		29.5	31.1	30.6	4.6	6.1	5.5	9.0	10.7	10.0
Max		32.7	35.5	33.9	5.9	7.2	6.4	10.7	12.2	11.4

Table 30. Hunterlab values for whole grain (with NaOH treatment) and percentage
Hunterlab for whole grain samples (NaOH treated)^z

Name	L NaOH			a NaOH			b NaOH			20°C		
	2002	2003	Mea	2002	2003	Mea	2002	2003	Mean	200	2003	Mea
ND690	26.9	29.0	27.9	6.5	7.9	7.2	11.3	12.8	12.1	94	100	97
W98616	29.4	29.9	29.6	6.8	7.4	7.1	13.1	13.7	13.4	6	3	4
AUS140	27.3	29.8	28.5	6.9	7.2	7.0	12.2	13.6	12.9	15	11	13
RL4137	20.2	20.5	20.3	8.0	7.5	7.8	7.5	7.5	7.5	2	2	2
LSD	1.3	1.0	1.1	0.5	0.4	0.4	0.7	0.5	0.6	27	19	22
Statistic	151 DH lines (n=151)											
Mean	28.1	29.5	28.8	6.6	7.6	7.1	12.3	13.3	12.8	64.	48.5	56.2
SD	0.8	10.0	0.8	0.3	0.2	0.2	0.5	0.5	0.4	20.	24.4	21.0
SE	0.1	0.1	0.1	0.02	0.02	0.02	0.03	0.04	0.04	1.7	2.0	1.7
Min	25.3	26.4	26.2	6.0	7.0	6.7	10.6	11.7	11.5	9.0	5.0	8.0
Max	30.2	32.1	30.6	7.2	8.2	7.5	13.3	14.3	13.8	98.	99.0	97.0

^z L = 100 (white) to zero (black); a = + (red); b = + (yellow).

Table 31. Analysis of variance for grain (without/with NaOH) and percentage germination for 155 wheat genotypes.

Source of variation	DF	Grain			Grain (NaOH treated)			Germination at 20C (1wk)
		L	a	b	L	a	b	
-----Mean squares-----								
Years (Y)	1	1528.1	642.5	795.5	619.9	293.0	328.9	71957.2
Locations (L)	1	0.2	46.5	49.7	1.5	67.8	27.2	30541.7
Y x L	1	15.3	67.2 **	52.5 **	65.6 *	35.9 *	27.9	48187.8 **
Replications (YL)	4	3.3 **	0.9 **	2.0 **	5.8 **	2.4 **	7.8 **	1303.8 **
Genotypes (G)	154	3.6 **	0.3 **	0.7 **	8.9 **	0.3 *	3.0 **	3915.3 **
G x L	154	0.7	0.1	0.1	0.7	0.1	0.2	278.0
G x Y	154	0.7	0.1 **	0.2 **	1.3 **	0.2 **	0.4 **	473.6 **
G x Y x L	154	0.6 **	0.1 *	0.1 **	0.7 **	0.1 **	0.2 **	275.9 **
Error	616							

*, ** Significant at P=0.05 and P=0.01, respectively.

Correlation coefficients among Hunterlab values for whole grain (without and with NaOH)

		Whole grain			Whole grain (NaOH treated)		
		L	a	b	L NaOH	a NaOH	b NaOH
2002	a	0.15	-	-	-	-	-
	b	0.68 **	0.66 **	-	-	-	-
	L NaOH	0.53 **	0.31 **	0.61 **	-	-	-
	a NaOH	0.12	0.55 **	0.39 **	-0.10	-	-
	b NaOH	0.54 **	0.44 **	0.71 **	0.95 **	0.03	-
	20C	0.07	-0.11	-0.09	0.08	-0.17 *	0.06
2003	a	-0.32 **	-	-	-	-	-
	b	0.61 **	0.43 **	-	-	-	-
	L NaOH	0.54 **	0.19 **	0.67 **	-	-	-
	a NaOH	0.06	0.25 **	0.28 **	-0.25 **	-	-
	b NaOH	0.57 **	0.27 **	0.79 **	0.94 **	-0.05	-
	20C	-0.06	-0.01	-0.03	-0.02	0.20 **	0.02
Averaged	a	-0.08	-	-	-	-	-
	b	0.67 **	0.51 **	-	-	-	-
	L NaOH	0.57 **	0.24 **	0.69 **	-	-	-
	a NaOH	0.08	0.36 **	0.25 **	-0.27 **	-	-
	b NaOH	0.58 **	0.36 **	0.80 **	0.95 **	-0.10	-
	20C	-0.01	-0.02	-0.03	0.03	0.01	0.05

*, ** Significant at P=0.05 and P=0.01, respectively.

Table 33. Means of grain (without and with NaOH) color values and percentage germination for 151 DH lines.

Trait	DH lines (n=151)		
	Year 2002	Year 2003	Difference ^Y
Grain ^Z			
L	31.0	33.3	-2.3**
a	5.2	6.7	-1.5**
b	10.0	11.5	-1.5**
Grain (NaOH treated)			
L	28.1	29.5	-1.4**
a	6.6	7.6	-1.0**
b	12.3	13.3	-1.0**
Percentage germination	64	49	15**

^Z L= 100(white) to zero (black); a = + (red); b = + (yellow).

^Y 2002 average minus 2003 average for a given trait.

** Significantly different from zero at P=0.01.

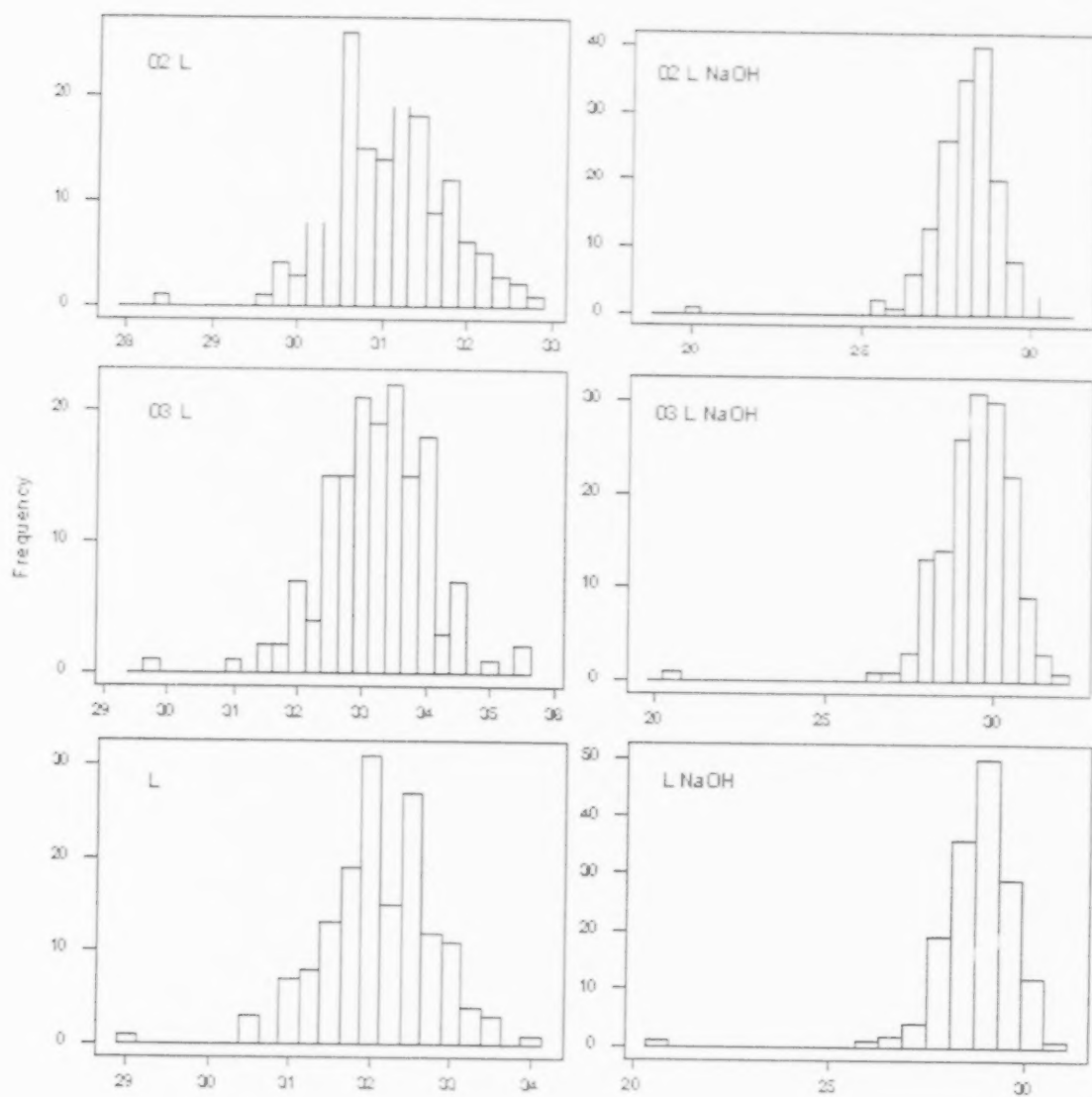


Figure 4. Frequency distribution of L Hunterlab values for 155 lines. Top left=2002 means; middle left=2003 means; bottom left=combined means; Top right=2002 means NaOH treated; middle right=2003 means NaOH treated; bottom right=combined means NaOH treated.

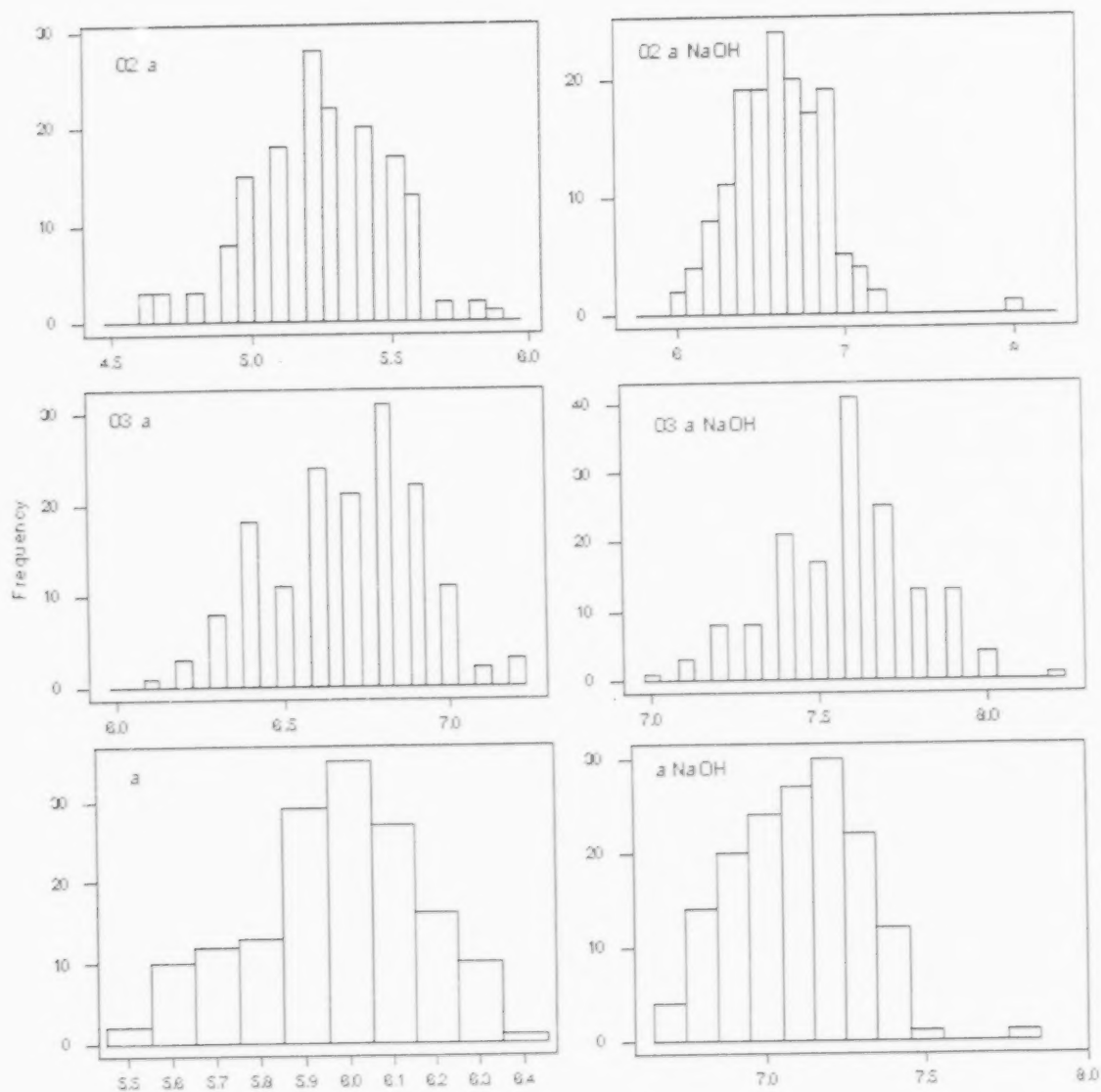


Figure 5. Frequency distribution of a Hunterlab values for 155 lines. Top left=2002 means; middle left=2003 means; bottom left=combined means; Top right=2002 means NaOH treated; middle right=2003 means NaOH treated; bottom right=combined means NaOH treated.

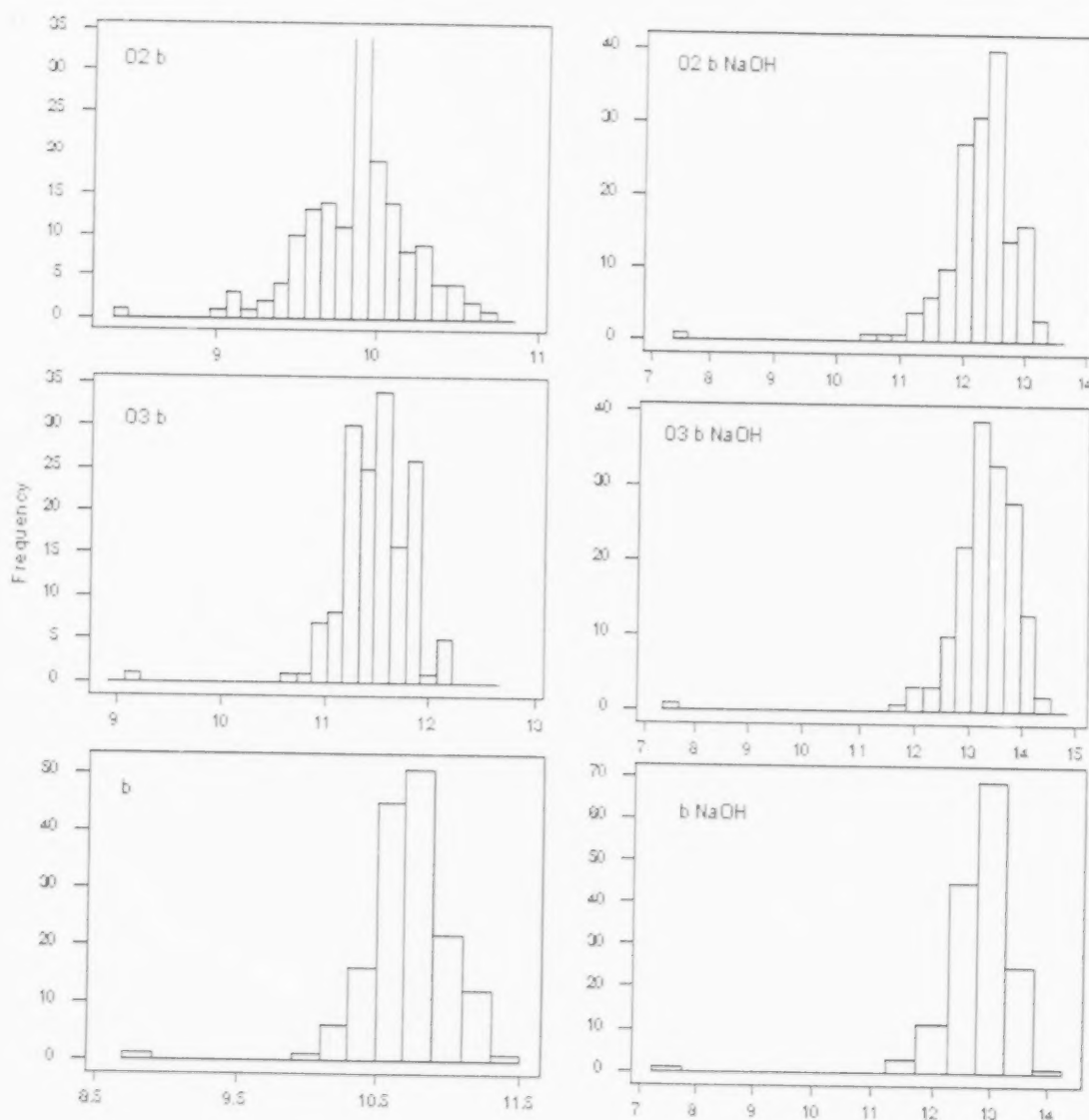


Figure 6. Frequency distribution of b Hunterlab values for 155 lines. Top left=2002 means; middle left=2003 means; bottom left=combined means; Top right=2002 means NaOH treated; middle right=2003 means NaOH treated; bottom right=combined means NaOH treated.

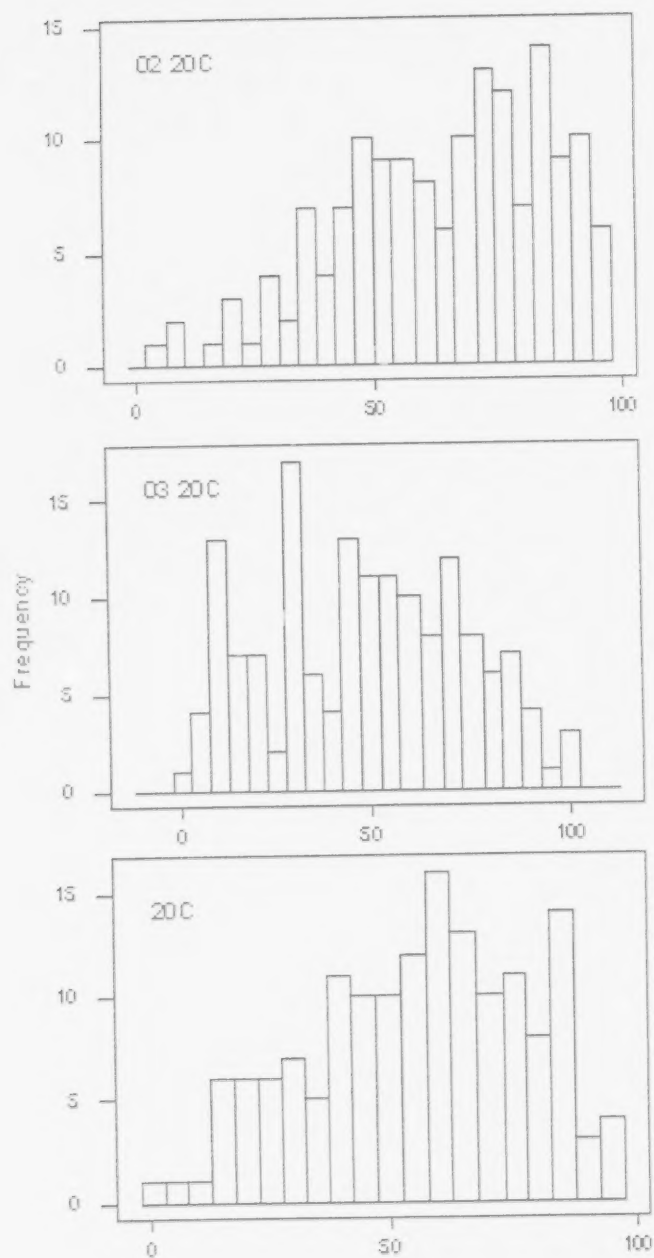


Figure 7. Frequency distribution of percentage germination at 20°C for W98616, ND690, and 151 DH lines. Top=2002 means; middle=2003 means; bottom=combined means.

